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REPORT 113

EARTH RESOURCES SURVEY APPLICATIONS OF THE SPACE SHUTTLE SORTIE MODE

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FOREWORD

This study has been performed for the NASA Office of Applications in support of the joint NASA-User Agency planning for maximum utilization of Shuttle-Sortie missions in furthering Earth Resources Survey development. Some initial study work in this area done for NASA by Dr. Ravi D. Sharma and Mr. William L. Smith while at Bellcomm, Inc., has served as a starting point for the study effort described in this report.

The authors are appreciative of the advice and comments provided by Mr. Charles W. Mathews, NASA Associate Administrator for Applications and others in NASA and in the federal user agencies. The authors particularly acknowledge the useful advice and comments of Dr. Archibald B. Park, former Chief of the Earth Resources Survey Program, NASA, and Dr. Martin W. Molloy, Earth Resources Survey Program, NASA. The NASA Technical Monitor was Mr. Luke L. Liccini, whose support contributed to the effective completion of the study.

Dr. Sharma served as a consultant to System Planning Corporation (SPC) for the study prior to undertaking his present assignment at the Indian Space Research Organization, Bangalore, India. Mr. Fred J. Thomson of the Environmental Research Institute of Michigan, also served as a consultant to SPC for the study, particularly in the role of atmospheric effects on remote sensing measurements. The suggestions and general guidance of Dr. Robert A. Summers, who undertook SPC management responsibility for the project, are also appreciated.

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A. INTRODUCTION

A balanced and proper utilization of natural -- both renewable and non-renewable -- resources is necessary if the U.S. is to continue to build economic strength while maintaining acceptable levels of environmental quality. The information systems gathering data on available resources within the U.S., if integrated with those outside the U.S., could provide global resource information of considerable economic importance to industries, governments and international organizations. Remote sensing techniques are, of course, only one of the several ways by which such resource information can be gathered. In some situations remote sensing can replace conventional methods of gathering information. In some cases it can provide supplementary information to that collected by other techniques such as ground surveys while in other cases the remote sensing techniques may not be applicable or may have limitations so as to reduce the effective utilization of that information.

Even when the remote sensing techniques are applicable to a resource management problem of economic importance, choices can be made among a variety of potentially available platforms including balloons, aircraft, helicopters, rockets, unmanned satellites and manned spacecraft. The platform considerations are also closely related to the choice of the frequency of observations, which, in turn, must be commensurate with the observable temporal changes in the phenomena. The aerial platform provides certain advantages in some situations, for example, in the case where the area to be surveyed is not too large and frequent repetitive coverage is not required. The advantages and disadvantages of aircraft versus satellite surveys have been debated in the literature. However, the feasibility of doing earth resources surveys with the use of a satellite has now been demonstrated by ERTS-1, particularly where the areas to be surveyed are large, the information is to be handled on a national level, and/or repetitive coverage is needed. The choice of a system, therefore, depends upon the spectral range and the channels required, on the frequency of observation and on the spatial resolution among

B. OBJECTIVES

The objectives of this study include the following:

1. To review ERS program application objectives and related resource management activities for the purpose of identifying some of the applications which are closely related to advanced R&D (i.e., this includes supporting development of a second-generation operational ERS system).

2. To identify those Shuttle Sortie mission capabilities which relate to this advanced ERS R&D.

3. To define, within an ERS discipline area and for one or more selected application objectives, experiment concepts which exploit the special features of a Sortie mission and/or which could be uniquely accomplished by means of a Sortie mission.

4. To consider the payload concepts required to carry out Sortie-based investigations and the potential impacts on mission characteristics.

C. ORGANIZATION OF STUDY REPORT

A resource management "total-system" approach is discussed in Chapter II as a context for the study. Sortie capabilities and modes of use are discussed in Chapter III. In Chapter IV, the application objectives covering major resource disciplines are discussed with special reference to the Shuttle Sortie missions. In Chapter V, an example of vegetation canopy model experiment is presented as a unique application of Sortie missions following which (Chapter VI), as an example of common factor entering into a remotely-sensed data, the atmospheric effects are discussed. Chapter VII addresses a potential growth area covering international aspects of the Sortie missions. Chapter VIII provides the summary conclusions and recommendations.

CHAPTER II

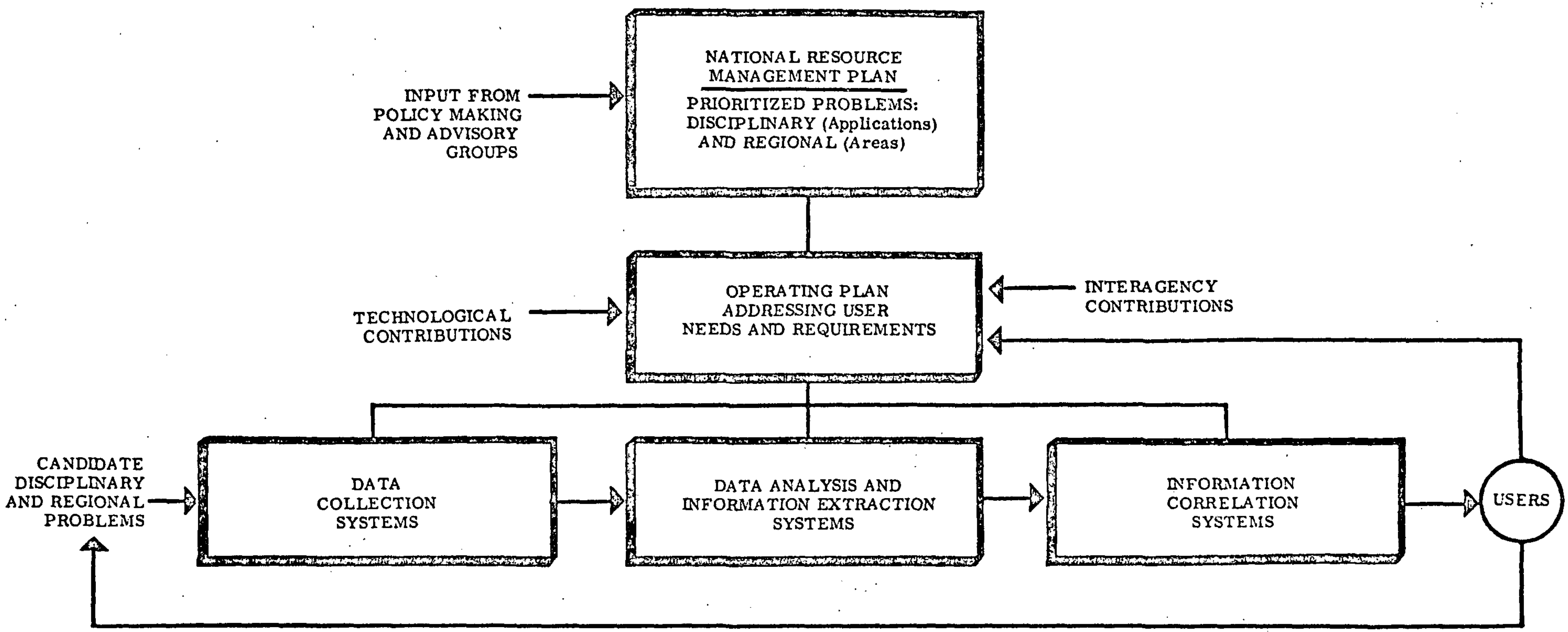
APPROACH

A. A TOTAL SYSTEMS CONCEPT

An outline of a remote-sensing-assisted total resource management system designed to solve a problem posed by a user is shown in Figure 1. The development of such a system should begin with a user and his problem. To solve his problem, the user requires information which is extracted from data collected by various sensors. These sensors may be located on the ground, on aircraft, or on satellites. The satellite platforms include long-period or low altitude orbitors, geostationary types, and Shuttle Sortie missions. Table 1 outlines the various data collection systems considered.

Data from the sensors must be processed and analyzed in order to present relevant information to the user. The importance of processing has generally been recognized by many users of remote sensing data in (1) reducing the amount of material which must be examined by humans to the most pertinent material and (2) presenting complicated information in a readily assimilated form, e.g., color coded displays, tables of areas recognized, statistical summaries. Table 2 shows a generalized data analysis and information extraction route. Table 3 lists the elements of information correlation. Processed data generally is stored in some correlator for access by users. In reality the correlator merges diverse sources of information and may also feed back to the information extraction operation such important information as atmospheric corrections, location of training sets, etc. Although the correlator is generally conceded to be the responsibility of the decision-making agency which the user represents, its general utility is not only to furnish information to the users, but also to the people who must process the data to extract the pertinent information. A particular example of the latter is the furnishing of previously collected data to the processors to complete a multi-temporal signature analysis. Additionally, the correlator will incorporate predictive and interpretive models which the users will have developed. These models will include a capability to calculate effects at times when remote sensing measurements are not available.

FIGURE 1. RESOURCE MANAGEMENT - A SYSTEMS APPROACH



DATA COLLECTION SYSTEMS

- SENSORS (IMAGING PHOTOGRAPHIC, LINE SCANNING OR IMAGING ELECTRONIC, AND NON-IMAGING)
- HUMAN INTERFACE
- GROUND SYSTEMS
- AIRCRAFT SYSTEMS
- AUTOMATED SATELLITES
- "IN SITU" PLATFORMS (CONTACT MEASUREMENTS)
- SPACE SHUTTLE
  - — SATELLITE LAUNCH, STAGING, REPAIR, RETRIEVAL AND REPLACEMENT
  - — SORTIE MISSIONS
    - R&D MODE
      - INSTRUMENT AND TECHNIQUE DEVELOPMENT
      - FACILITY (TEST AND VERIFICATION OF DISCIPLINARY APPLICATIONS, INCLUDING PALLET MODE)
    - LIMITED OPERATIONAL MODE
    - CONTINGENCY MODE (VARIETY OF ABOVE WITH RESPONSE TIME ELEMENT)

TABLE 2

DATA ANALYSIS AND INFORMATION EXTRACTION *

- DATA FORMATTING (DIGITIZATION, COMPUTER COMPATIBLE, A/D-D/A, ETC.)
- EDITING (SPATIAL, TEMPORAL AND SPECTRAL) AND COMPACTION
- DATA ANALYSIS (CREDIBILITY EXAMINATION, ATMOSPHERIC CORRECTIONS, CALIBRATION)
- PROCESSING TECHNIQUES
  - DEFINITION (CRITICAL STEP) - INCLUDES PREPROCESSING SUCH AS EMPIRICAL FUNCTIONS TO REMOVE ILLUMINATION VARIATION AND PROCESSING ALGORITHMS SUCH AS PATTERN RECOGNITION, MULTISPECTRAL DISCRIMINATION AND CLUSTERING APPROACH.
  - IMPLEMENTATION (TIME CONSUMING, REPETITIVE, MAY BE EXPENSIVE OPERATION - OPTIMIZATION TECHNIQUES MAY HELP)
- POST-PROCESSING ANALYSIS (ESTIMATION OF ERRORS, FURTHER ANALYSES SUCH AS GENERATING STATISTICS, ACREAGE, PERIMETER ETC. FROM MAPS AND CATEGORIZATION)
- DISTRIBUTION TO USERS AND CORRELATION WITH OTHER SENSORS AND PLATFORM SYSTEMS

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* ALL STEPS ARE NOT NECESSARY FOR EVERY PROBLEM

TABLE 3

INFORMATION CORRELATION

- RETRIEVAL OF INFORMATION IN USER REQUIRED FORMAT
- MULTI-SENSOR/MULTI-PLATFORM INFORMATION STORAGE AND CORRELATION
- MULTI-TEMPORAL INFORMATION CORRELATION
- COMMON BASE MAP OR GRID FOR CORRELATION
- INTERPRETIVE AND PREDICTIVE MODELS (MODELS HELP PREDICT CRITICAL OBSERVATIONAL PARAMETERS SUCH AS TIME OF OBSERVATION, ALTITUDE, SUN AND VIEW ANGLES, WAVELENGTH, ETC.)
- RESOURCE MANAGEMENT MODELS

  IMPACT OPERATIONAL DECISIONS, E.G., SCHEDULING OF IRRIGATION WATER (INCLUDING AUTOMATIC OFF-ON, ETC.

  IMPACT PLANNING AND FORECASTS
- ECONOMIC ASSESSMENT/ALTERNATIVES AND OPERATIONAL PLAN IMPACT
- USER OPERATED/PROBLEM DEPENDENT CORRELATOR MAY BE PREFERRED RATHER THAN CENTRAL FACILITY

Today, no entirely satisfactory operational plan can be advanced for any earth resources problem. This is because of the relative lack of experience with satellite remote sensing data and because of the advance beyond the feasibility study stage in only a few discipline areas. Experience with ERTS-1, ERTS-B, and Skylab data should provide much of the needed experience with satellite data. Some quantitative ideas about an optimum mix between repetitive satellite, aircraft, and ground measurements for solving particular problems may be forthcoming from these programs, but more study will probably be needed to quantify these experiences and put them in proper perspective. This will be important in order to assess the contribution that various Shuttle-Sortie-based sensor systems can provide to the solution of problems.

B. SENSORS FOR SHUTTLE SORTIE MISSIONS

Many different sensors can be used for Shuttle/Sortie missions, depending on the phenomena being investigated. The likely useful sensors fall into four main groups: imaging photographic sensors, imaging or line-scanning electronic sensors, non-imaging electronic sensors, and non-imaging photographic sensors. Exactly which sensors or combination of sensors are required for Shuttle Sortie applications needs to be defined for each proposed application. Detailed consideration must be given to how the data will be processed or interpreted and what information the interpreted results will provide.

Some general comments may be made about the suitability of sensors for Shuttle Sortie mode applications. To make optimum and timely use of Shuttle Sortie information, many applications will require some form of automatic processing and storage. The imaging or line-scanning sensors are clearly advantageous for these applications because the format of the output data is directly compatible with computers. Because the data format can be made compatible with telemetry links, rapid transmission of raw or processed data is possible.

Photography will continue to have superiority where very high spatial resolution is desired. However, on-board photographic processing of color materials requires further development before such imagery can be analyzed on-board the Shuttle. Also some means of getting information deduced from photo-interpretation into computer data bases is required.

Active and passive microwave sensors will prove superior where "all weather" capabilities are desired and where phenomena being detected are particularly well suited to these sensors. More work needs to be done in determining the feasibility of solving various earth resources problems with these sensors, on automatic processing of their outputs, on registration in data bases, and on knowledge of the physical phenomena being detected.

C. REQUIREMENTS OF A DATA PROCESSING AND ANALYSIS SYSTEM

Data processing and analysis of raw sensor output is an important component of the total information extraction process for any earth resources survey system. The present discussion is presented assuming that computer-aided information extraction will be extensively employed. The general concepts apply to any information extraction system.

The data processing and analysis portion of information extraction generally consists of seven steps:

(1) data formatting
(2) editing
(3) data analysis
(4) processing technique definition
(5) parameter definition and processing implementation
(6) post-processing analysis
(7) storage

Data formatting is the operation of getting raw sensor data into a convenient form for further processing. It may consist of digitizing photography, decompressing compressed data, or analog-digital or digital-analog conversion.

Editing is the operation of reducing the amount of data to be analyzed. It may consist of selection of portions of scanner runs, of areas of a photography or of spectral regions of spectrally-scanning radiometer output.

Data analysis is the operation of examining the data to determine if it is credible (sensor working properly) and to determine if atmospheric or other degrading effects need correction. Analysis results can often provide considerable insight to the processing technique to be used.

Processing technique definition is really self-explanatory. A proper processing technique is one which accounts for data artifacts determined from analysis and which provides information required by the user (although may be not in final form). As such, it is the most crucial step in the processing. This step may be arbitrarily divided into "preprocessing" and processing. In preprocessing, the data are usually transformed so that various assumptions of the processing algorithm (e.g., invariance of spectral signatures) are more nearly satisfied.

Parameter definition and processing implementation are the operations of extracting parameters (e.g., signature means and covariance matrices) for the processing operation, then implementing the processing. Optimum channel analysis, typically performed in the data analysis phase, also impacts this operation through the definition of a good subset of channels. Processing implementation may easily be the most time consuming operation in information extraction, especially if large amounts of data are to be processed.

Post-processing analysis is the operation of further analyzing the processed output to determine particular parameters of interest to the user. An example might be the further analysis of a water recognition map to determine the number of standing water bodies and their size and perimeter.

Finally, storage involves the storing of the information in the users correlator. Implicit in this step are reformatting operations and/or data transmission over wire or telemetry links.

D. CORRELATION SYSTEMS

Correlation systems, the next step in the information extraction process, are important parts of any earth resources system because they permit decision makers to obtain needed information in a timely fashion. For data collection rates as in ERTS-1, it has become apparent that computer-based information

systems are required. But correlators can do a lot more than simply catalog data or information. The correlator must support a retrieval system so that investigators can obtain the information they require (and only that information) from the system in a format suitable to their needs. Because various users may want different formats and different information, the design of such a system is not trivial.

In addition to a retrieval system, various predictive and interpretive models will annually be incorporated in the correlator. The predictive models serve at least two useful purposes: (a) they allow prediction of effects or phenomena when remote sensing data are not available, but some estimate of conditions is required; (b) these models also allow estimation of proper times to collect additional remote sensing data. They thus serve mission planning requirements and thus impact the operational plan.

E. IMPLICATIONS FOR SHUTTLE OPERATIONS

The design of appropriate sensors and on-board information extraction systems is important if the unique capabilities of the Shuttle are to be exploited. The sensor and information extraction systems should really be designed together to minimize problems such as in the data formatting area.

In general, there is a trade-off between the data transmission requirements and on-board equipment complexity as suggested in Figure 2. The curve is discrete, because finite jumps in equipment complexity are required to reduce data transmission rates. Further, a point of diminishing returns is reached where further data rate requirements are obtained only at the expense of sizably more complex hardware and perhaps human interaction. Point A represents, for example, telemetry of raw multispectral scanner data, B represents the introduction of an efficient channel selector and optimum data encoder, and C represents the introduction of on-board pattern recognition.

Projections of the present state-of-the-art in processor design indicate that a complete on-board pattern recognition processor probably could be built within the Shuttle weight and power limitations. However, the question is whether the

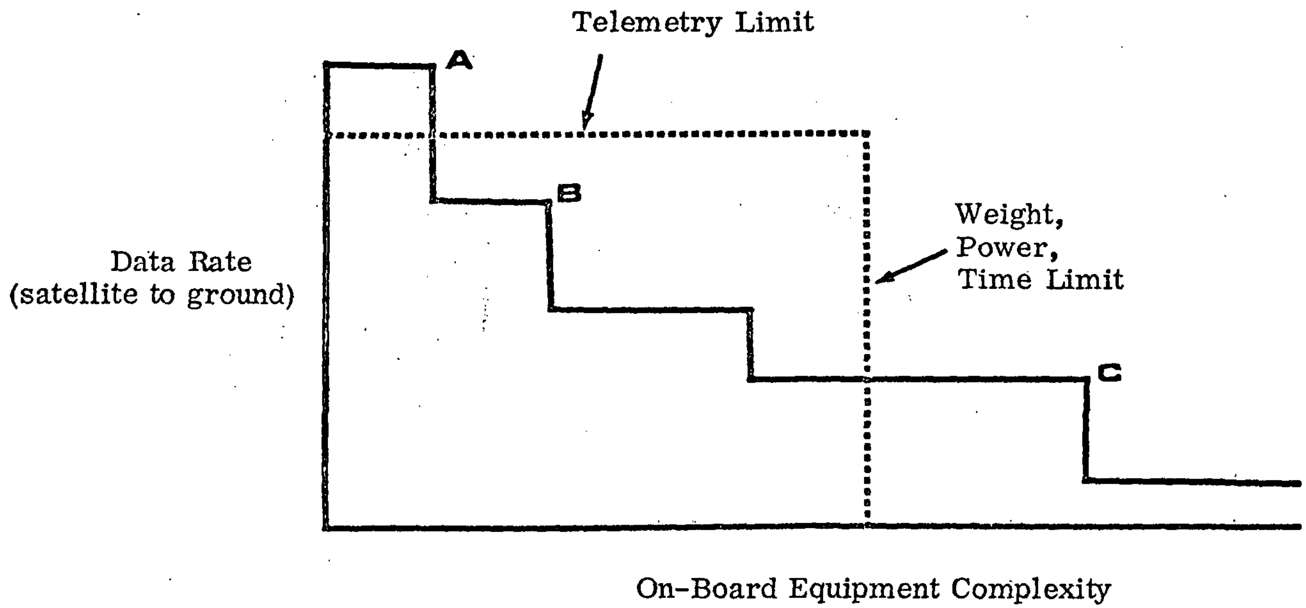

FIGURE 2. DATA TRANSMISSION REQUIREMENTS, AS RELATED TO ON-BOARD EQUIPMENT COMPLEXITY

on-board scientist or mission specialist would be able to use the device effectively. If accuracy requirements are not too severe and the astronaut has a prior knowledge of the location of adequate training sets, processing of 15 minutes of scanner data from a typical spacecraft scanner (such as ERTS-1 multispectral scanner) could be done in about one hour. However, the astronaut probably would have to be extremely lucky (and require a lot of ancillary information) to be able to make this operation succeed.

Some tradeoff, short of the complete on-board processing point, seems reasonable at this time. Considerably more systems study needs to be undertaken to design candidate systems which effectively balance on-board equipment complexity with data transmission requirements. At some point, it will undoubtedly be cheaper to build prototype systems and test them on Shuttle Sortie missions in order to identify the most effective one.

The configurations arrived at may be very application (discipline) dependent, so that an optimum sensor-processor system may be difficult to identify. However, it should be possible to find a number of good multiple-use systems. The problem is made more complicated by the need to consider the Shuttle/sensor/processor package as only one part of a comprehensive ground, aircraft, and satellite system. There may be more long-range benefit derived from Shuttle Sortie collected data used in this way than in Shuttle Sortie data collected along to solve a problem for which Shuttle Sortie data is uniquely required.

Considerably more systems study is required to define payloads most suitable for Shuttle Sortie testing. It may be possible to implement systems which solve a number of anticipated problems well (although none may be solved optimally). This may be a reasonable engineering approach since the costs of hardware development can be written off over several applications. Additionally, much more development is required on information systems for managing remote sensing data. Design of these systems necessarily involves close interaction between the user and the technologist to identify and implement the required features.

CHAPTER III

SORTIE CAPABILITIES AND MODES OF USE

A. GENERAL

Earth applications studies are particularly suited to Shuttle Sortie missions for purposes of instrument development, for the study of short-term phenomena and for sensing selected targets. The proposed polar Sortie missions of seven days duration at 100 nm are readily adaptable to Earth Resource Survey Applications requirements. For such missions experimental payloads may comprise both developmental and operational experiments. The developmental experiments would include those of an engineering research or laboratory nature such as improving the resolution of a spectrometer. Operational experiments would include surveys of slowly varying phenomena such as delta or coastal studies, agricultural and forestry patterns, those requiring intermittent observations rather than constant surveillance.

In this overview of the relationship of multidisciplinary earth resources applications to the Sortie missions, only a very few selected facets of the Shuttle applications program are considered. Since these applications are dynamic, any description of the current state-of-the-art of earth observations with respect to the Shuttle will only serve the purpose of indicating the general direction of the program. If one were to propose a payload based on today's technology, it would not be difficult at all; the problems arise due to attempted projections into the future. Conclusions based on specific hardware need to be made with caution, inasmuch as hardware technology in this field is progressing dynamically. The Shuttle program in general, and the Sortie mode in particular, have to be developed with the understanding that "earth observation" techniques and instrumentation include

a conglomeration of instruments coming from a variety of conventional disciplines such as astronomy, optics and electronics and many of these have had a long history of instrument and technique development. Although the limits of existing instrument hardware have not yet been fully exploited, the urgent needs for earth observations are not in advancing the instrumentation per se, but are in the area of defining the information requirements, in obtaining related data and in their interpretation. These activities can be supported by three types of platforms, successively emphasizing instrument development, applications facility optimization and operations.

B. PROGRAM INTERRELATIONSHIP

The EREP payload on Skylab has been selected to provide a substantial advance in spectral range and spatial resolution capability. It is a developmental payload which has limited sensor variation and experimentation and testing capability. In the case of a Shuttle payload, the instruments may be only simple modifications of laboratory type equipment in many cases, and thus development and modification of a sensor either in flight or upon return to the ground are possible. In either case, the time lapse between different versions of the instrument can be reduced by multiple short duration missions.

The Space Shuttle Sortie Program would be an ideal place for the initial space flight of an instrument. The stage of sensor development would be similar to aircraft flights inasmuch as the instrument would be accessible to the technician or scientist for in-flight calibration and adjustment. There is also an advantage in retrieving prototype instrumentation after a short flight for modification and improvement for subsequent Shuttle or operational flights. Such methods would be conducive to rapid progress in bringing complex multispectral instruments to an optimum state of performance.

The Sortie mode will permit scientists from various earth resource disciplines to participate in target selection and sensor development and assure the best possible reliability of instrument performance. The Shuttle's capacity for a large earth resources experiment payload will make it possible to cover the electromagnetic spectrum from the visible, through IR, and active and passive

microwave regions, and in many instances permit intercomparisons of two or more types of sensors. The Shuttle will be able to carry instruments representative of the best available technology as to optimum spectral and spatial resolution, as well as the sensors which are under development. The technician-engineer or scientist on-board will be in a favorable position to sound the atmosphere in the IR and microwave regions in order to establish, and adjust for, the effects of atmospheric attenuation on data, and to undertake a study of on-board data handling. Benefits derived from Shuttle mode experiments will be adapted to the remote sensing programs of the automated earth resource operational satellites.

C. INSTRUMENT DEVELOPMENT SORTIES

Instrument development Sorties will be a small, but critical phase in the aircraft-type mode of Shuttle use. Here any new conceived ideas or previously untested or only aircraft tested instruments will be 'field' tested in orbit. This is the mode in which a General Purpose Payload module would be assigned to earth observations disciplines.

In one mode of operation, several mission specialists could be carried aboard to crystallize the problems or capabilities of certain sensor systems for solving a particular application problem. This could require a sensor development effort, a phenomena detection effort, and some data analysis, each possibly requiring individuals familiar with these areas. There could be several such sensor test projects in one Sortie mode. Thus, e.g., an instrument engineer, a hydrologist, and a computer analyst would all go on one Sortie flight and interact in orbit to best optimize their system for a given set of applications in hydrology.

Another mode of Shuttle Sortie mission usage could be comparative sensor development. In this mode one would carry out a comparative study to evaluate the potential of various sensors available in the market. Engineers could be allowed to experiment with their own developments and inventions/modifications so as to optimize various parameters. Table 4 lists the elements of an instrument development sortie to field test instruments in orbit.

INSTRUMENT DEVELOPMENT SORTIE

TO FIELD TEST INSTRUMENTS IN ORBIT

- SEVERAL SPECIALISTS, SENSOR SYSTEMS, AND PROCESSING SYSTEMS
  - -- INSTRUMENT ENGINEER, HYDROLOGIST, GEOLOGIST, COMPUTER ANALYST
- SEVERAL EXPERIMENTS ON ONE MISSION
- NEAR REAL-TIME ANALYSIS AND CORRELATION OPTIMIZES PROGRAM
- INSTRUMENT DEVELOPMENT TIME SHORTENED
- MORE RAPID CHANGES IN PROGRAM POSSIBLE
- SOME PAYLOADS NOT COMPATIBLE WITH SATS, ERTS, OR NIMBUS R&D PLATFORMS
- COMPARATIVE SENSOR DEVELOPMENT
  - -- EVALUATE SEVERAL INSTRUMENTS
  - -- EXPERIMENT WITH INSTRUMENT MODIFICATIONS
  - -- PERFECT MODELS OR VERSIONS OF INSTRUMENTS
- SOME CHARACTERISTICS ONLY DISCOVERABLE DURING ACTUAL FLIGHT CONDITIONS
- EXCESSIVE DEPENDENCE ON THEORETICAL UNDERSTANDING ELIMINATED

There are several modes in which a facility (Dedicated Module) can be used in a Sortie mode. In addition to a payload like EREP, there would also be data management equipment aboard. These could include computers, both digital and analog, with cathode ray tube or luminescent diode display facilities. One mode in which an 'observer' could use such a facility would be to display only the parameters of interest to him. For example, if one were interested in identifying lakes along a given orbital track for hydrological studies, then one could first identify a 'learning set' of lakes known from ground truth. This would permit selection of a given channel or channels, correlation among which implies identification of water bodies along a flight path. Under actual flight conditions the computer could be trained to accept a certain correlation among multispectral scanner channels as water bodies, either lakes or rivers. This set could then be used as a reference by the on-board computer memory and then would be extended in the flight path for further lake identification. Such identification techniques through initial learning sets have been carried out with aircraft by the University of Michigan and provide some confidence for extension over 40-50 miles. The assertion that makes such a study possible from Shuttle Sortie Dedicated Module 'Facility' is that frequent flights are available so that studies of individual subjects are possible in a given Sortie flight using an instrument such as the scanner.

Perhaps half a dozen instruments with corresponding observers/experimenters could easily be carrying out such data optimization studies. They could use experiment peculiar data display/reduction equipment as well as a small central computer. The most likely class of observers are professional geologists, hydrologists, meteorologists, etc., perhaps supported by an optics technician or engineer. These observers will optimize these instruments for various phenomena. For example, they could experimentally determine whether only a certain number of channels will be needed on a scanner for hydrological and oceanographic applications. They could also shed light on how different the disciplinary goals have to be (e.g., urban planning versus oceanography) before one needs two different instruments optimized with respect to the resolution for each discipline. Also, it could be determined to some extent as to what phenomena or signatures are determinable from space and under what conditions.

Often a trained professional can detect phenomena which could easily escape the untrained or uninterested eye. For a geologist or an oceanographer, the challenge is enhanced with experience and for the first time such mission specialists can go on a Sortie flight in space. Phenomena which essentially manifest themselves in only large area photographs include cloud patterns at land-sea interface, geological lineations and faults. There are, however, many more subtle features that a scientist or engineer knows of in his own field and would be easily able to identify. Thus, the long and laborious procedure of inculcating an astronaut with multidisciplinary resource knowledge could be simplified with the introduction of principal investigators on the Sortie. Table 5 lists the essential elements of a facility or dedicated module.

D. PLATFORMS

The need to develop the facility program derives from the ultimate goals of the earth resources survey disciplines, which are to ensure global monitoring for various applications, providing status reports similar to that provided by Nimbus-type platforms. The "facility" is regarded as a step toward those automated platforms which will carry only proven and tested sensors capable of observing known phenomena. In the 1980's these could be regional geosynchronous earth observation satellite. The purpose of these geosynchronous platforms would be to monitor regional or continental areas with sensor capabilities optimized so that these have long operational lifetimes. We are far from putting up such operational application satellites today. This is unlike the communications field with Intelsat type satellites. The gap is partly technological, i.e., lack of appropriate instrument sensitivities; however, it is a gap which is finite and, with appropriately initiated R&D programs, it will be possible to reach the required sensor performance in the 1980's. Astronomy and microwave and laser technologies developed for applications elsewhere will be helpful in advancing earth observations, especially with an increased weight carrying capacity to geosynchronous and high polar altitudes by utilizing the Shuttle and Tug (or stage) type of configuration. The major gap in becoming operational is thus not instruments or technology, but identification as to what phenomena can be observed

TABLE 5

FACILITY OR DEDICATED MODULE

- LARGE FIXED SENSOR PAYLOAD, DATA MANAGEMENT EQUIPMENT, DISPLAY FACILITIES
- MISSION SPECIALIST DISPLAYS ONLY PARAMETERS OF INTEREST. CHANNELS SELECTED DURING FLIGHT ALONG SELECTED FLIGHT PATH
- MANNED SORTIE PROVIDES IMPROVIZATION CAPABILITIES, EXPLOITS INHERENT MOTIVATION OF SPECIALISTS
- SEVERAL EXPERIMENTERS WITH CORRESPONDING INSTRUMENTS MAY UNDERTAKE DATA OPTIMIZATION STUDIES
- PROFESSIONAL OBSERVERS (HYDROLOGISTS, GEOLOGISTS) MAY EXPERIMENTALLY IDENTIFY PHENOMENA OR SIGNATURES.
- A TRAINED PROFESSIONAL CAN DETECT PHENOMENA WHICH WOULD NOT BE NOTICED BY UNTRAINED OBSERVER
- DATA TO BE USED FOR VERIFYING DETECTABILITY OR PREDICTABILITY OF A RESOURCE -- NOT FOR GLOBAL INVENTORY
- <u>PALLET MODE</u> OFTEN CAN REDUCE NECESSITY OF DISCIPLINARY SCIENTISTS BEING ON-BOARD, YET PROVIDE NEAR REAL-TIME DATA AND EFFECTIVE TEAM INTERACTION.

from space, who will benefit from such data, and what are the information needs in a given discipline. These capabilities can be easily demonstrated by early 'facility' flights from the Shuttle. Thus, a big unknown about the operational success of a 'platform' is considerably reduced. Such a 'facility' will assist in evaluation of the sensor performance and disciplinary information needs such as optimum modes for data collections. Hence, a large variety of activity will be carried out on the facility to bridge the gap between R&D and operational satellites in earth observation disciplines.

E. DISCUSSION

Considering the Shuttle Sortie mission capabilities in terms of the resource investigation process, it is possible to identify certain aspects of the program which can be utilized in mission planning. It would appear that instrument development and competitive instrument evaluations are particularly suited for Sortie missions. It would also appear that the ultimate objectives in earth applications are operational data collection platforms either in high polar or geostationary orbits. The program is several steps away from launching such satellites today because of the needs for instrument development and needs for establishing reliable signatures and information requirements. The Shuttle Sortie is capable of assisting in both these areas in which an experimenter/observer interface can effectively be used. The information needs of the earth resource disciplines have arbitrarily been divided into a general purpose and a dedicated module approach. The instrument/sensor development seems best suited to the general purpose approach, while the disciplinary needs appear to be best met by a facility approach.

Some of the advantages of the Shuttle Sortie mode are:

- Short lead time for flight preparations
- Frequent flights
- Selection of desired orbit and inclination for each mission
- Possibility of real time data optimization or editing of data in real time
- Quick data availability

- Special missions for phenomena of interest (hydrology, floods, hurricanes, corn blight, snow fall, monsoons)
- Transient and meteorological phenomena helped by pointing capability and manned presence
- Investigator advances the disciplinary goals by becoming an observer and data collector
- Common equipment usage (central computer or standard laboratory type facilities)
- Laboratory type instrument development approach with various evolutionary models
- Use by multiple agencies such as research institutions, government centers, universities, industries, international and foreign agencies, which provide versatile use and generate new ideas and results.

Some disadvantages of the Sortie mode include:

- Lack of repetitive coverage
- Lack of large area or temporal coverage
- Lack of large amounts of data per mission over a given site

A list of the special characteristics of the Sortie mission pertinent to earth resources survey applications and a summation of situations where the Sortie is uniquely useful are given in Chapter VIII.

CHAPTER IV

APPLICATIONS OBJECTIVES

A. DISCUSSION

The broad objective of earth sensing studies from space is to contribute to the responsible management of natural resources and the human environment. Natural resources are limited either by quantity or geography and it is in our interest to maintain a global inventory of certain resources for purposes of effective planning. Remote sensing of earth resources has the potential of providing vitally needed data for attacking world-wide programs of such accelerating urgency as food supply, raw material and energy shortages and population pressures. Programs directed toward environmental monitoring, and surveys of mineral, agricultural, and water resources will be significant in providing economic and social benefits. Such benefits may include limiting various forms of pollution, as well as assuring the long-term availability of commodities essential to a growing population and the expectations of a rise in the world-wide standard of living.

The Earth Observations Program has had available to it a variety of data acquisition modes including aircraft, low-orbit satellites and geostationary satellites as well as ground systems. The Space Shuttle Sortie mode embodies some of the desirable features of the aircraft mode and the low orbit satellite mode to help achieve the objectives of the Earth Resources Survey Program. Earth resources studies which appear to be particularly suited to the Space Shuttle Sortie mode include those routine operational missions where adaptability, quick preparation and rapid deployment are important. In addition to such operational missions, appropriate studies may include the rapid assessment of large-scale events, instrument development, and the study of short-term phenomena. For such missions, instrument payloads may be aimed at both developmental experiments and demonstrations of operational utility. The developmental experiments may include instrument development of an engineering research or laboratory nature, as well as discipline-oriented data utilization investigations. The latter investigations for the Sortie case, as well as the utility demonstrations, would emphasize those resource problems requiring intermittent

observation rather than constant coverage. The instrument payloads may be developed via the traditional principal investigator route or may constitute data acquisition facilities. In general, sensor and other instrument development appears better suited for the former route while the disciplinary needs seem best met by the facility approach.

The Space Shuttle transportation system will carry instruments and personnel to and from low earth orbits and, in particular, will provide a unique opportunity for the development of remote sensing techniques for earth resources survey exploiting short-duration Sortie missions. These missions will, in many respects, be "aircraft-like" with relatively large payload and power capabilities; in addition, professional instrument engineers and remote sensing specialists will be able to accompany the payloads. Many investigators consider the manned laboratory essential for the undertaking of conceptual interpretive earth resource studies of any depth or perspective. These missions should be particularly suited for research and development tasks involving sensors, on-board data processing and display, and for the study of certain classes of resource and environmental phenomena characterized by short time constants. The potential impact of the on-board instrument engineer and remote sensing specialist in expediting system development and on the effective meeting of user needs is of particular significance. In view of the fact that an initial operational earth resources survey system is expected to be in use beginning with the 1978-1980 time period, the Shuttle Sortie mode may be looked upon as one of the development tools for a second-generation ERS operational system anticipated in the 1980's.

B. RATIONALE

A primary concern in the consideration of applications objectives is to determine from the users the nature of their interests and problems in order that NASA may plan its technical programs, aircraft and spacecraft investigations along appropriate lines. Although such an approach has been the intent of the first generation ERS program, by necessity, the development program has essentially provided new capabilities for the user to evaluate as to their usefulness for assisting with user problems.

In order to address the program applications objectives in terms of user needs, discussions have been held with the following persons who are cognizant of the various discipline and agency requirements:

- Mr. John Jarman, Civil Works Division, U.S. Army Corps of Engineers
- Mr. John J. Sherman III, NOAA/NESS, Spacecraft Oceanography Group
- Mr. William A. Fischer, EROS Program Manager, U.S. Geological Survey, Department of the Interior
- Dr. John M. DeNoyer, Director, EROS Program, U.S. Geological Survey, Department of the Interior
- Dr. Robert H. Miller, Agricultural Research Service, U.S. Department of Agriculture
- Mr. John D. Koutsandreas, Office of Monitoring, Environmental Protection Agency
- Dr. Martin W. Molloy, Office of Applications, NASA Headquarters
- Dr. Charles Weiss, Jr., Science Advisor, International Bank for Reconstruction and Development (World Bank)

These discussions have been particularly helpful in providing insight into potential user requirements for a second generation operational ERS system.

The focus of the present study is a matching of Shuttle Sortie mission capabilities with recognized program objectives and user needs. The aim is to address applications objectives areas rather than to select specific disciplinary or instrument development experiments. The applications objectives addressed are consistent with stated agency goals and are compatible with Sortie mission capabilities and constraints. The research objectives are considered in terms of the requirements and characteristics of the Earth Resources Laboratory Mission or the Contingency Mission as defined in the Preliminary Report of the Earth Resources and Surface Environmental Quality Working Group at the NASA/GSFC Space Shuttle Sortie Workshop, July 31 thru August 4, 1972.

C. EARTH RESOURCES LABORATORY APPLICATIONS OBJECTIVES

The ERS Program applications objectives and related resource management activities have been reviewed for the purpose of identifying some of those applications which will be most closely related to advanced research and development and, as appears feasible, to second generation ERS operational systems capabilities and requirements.

Initial appraisal of the Space Shuttle in Sortie mode indicates that a large number of earth resource applications are feasible. In particular, it appears that those applications which only require infrequent sensing, yet which require high quality data (e.g., imagery and photography for the preparation of maps) would be uniquely suited to the Sortie mode. Such missions would be at most seasonal, at the least one to two flights per year. Real-time and near-real time data applications have little operational role for the Sortie, except in the rare case of contingency missions are not suited for aircraft missions. In addition to specific disciplinary missions, much of sensor development and the development of analytical and interpretive techniques could be undertaken on Shuttle Sorties, inasmuch as simple instrument mounting and adjustments would be possible and investigator scientists/engineers would be on hand.

The detailed sub-disciplinary applications objectives which have been used in this study are adapted in part from the disciplinary goals and objectives list presented by the Earth Resources and Surface Environmental Quality Working Group in the Proceedings of the Space Shuttle Sortie Workshop, NASA/GSFC, July 31 to August 4, 1972. These were evaluated in terms of the following:

- Does the potential user consider the objective to be useful?
- Will a manned Shuttle Sortie mission provide the essential information?

Inasmuch as the selection of suitable applications objectives is largely conceptual at this point, it is sufficient that they satisfy this evaluation.

The following sections list examples of potential applications which were evaluated and considered suitable for the Shuttle Sortie mode. Accompanying discussions summarize the disciplinary objectives, define the information requirements, and indicate relationships to the Sortie mode.

Remote Sensing Applications Areas Pertinent to the Shuttle Sortie Mode

1. Agriculture, Forestry, Range

   a. Capabilities

   - Identify and monitor agricultural, forest and rangeland vegetation and related soil types
   - Detect and assess losses from disease, infestation, salinity, moisture stress, drought, fire and other adverse elements
   - Inventory crop, timber and rangeland vigor to predict yield and forecast storage and disposal

   b. User Objectives and Requirements

To date, remote sensing of agricultural targets has been largely at the monitoring and mapping level, whereas those applications which seem pertinent to shuttle sortie missions, although essentially monitoring and inventory, are concerned with prediction capability and management decisions. The USDA/NASA Corn Blight Studies have demonstrated the use of airborne sensors in producing data for thematic maps. Thermal infrared data from the Nimbus satellites have demonstrated seasonal vegetation changes. ERTS-1 imagery has provided information on soil type distributions. The Shuttle Sortie will permit intensive multispectral sensing to provide essential data for agricultural management and planning.

Multispectral imagery and photography of agricultural, forest and rangelands from Shuttle Sorties in the spring and summer, and again in the late fall should provide important information on vegetation-soils relationships. Remote readout of in situ sensors plus higher resolution local imagery from aircraft should serve in the evaluation of stress conditions of a seasonal nature. The presence of a mission specialist to select data channels, to modify sensor use and to select target areas will enable developing sensing techniques for obtaining the statistical information required to assess crop, forest and range vigor to permit estimations of probable yield and to identify areas where stress conditions will have a detrimental effect. The Shuttle Sortie missions will be only used where the spatial, spectral and temporal requirements are such that

those cannot be met by the data from automated operational satellites available at that time. For example, two weeks in a growing season for an economically important crop might be crucial for forecasting yield and vigor of that crop. In such identifiable cases, Shuttle Sortie incremental costs may be more than justified compared to potential value of the information returned from such a mission.

The Sortie role in mapping and monitoring of agriculture may be somewhat less critical for the U. S. than it would be for developing countries. If in the U.S., for example, the Department of Agriculture Statistical Reporting Services is considered highly accurate in its reported data, then the incremental benefits of remote sensing techniques to U. S. agriculture per se would not likely be large. In this case, the more likely Sortie role would be in the area of research and development considering such problems as automatic interaction with ground-based components (e.g., irrigation controls), or addressing stress situations (e.g., black fly or freeze in orchards).

2. Mineral Resources and Geology

a. Capabilities

- Identify geologic features which may aid in exploration for ores, fuels and geothermal power sources

- Monitor such dynamic phenomena as volcanoes, earthquakes and coastal processes, assess damage and undertake studies related to the prediction of hazardous events or conditions

b. User Objectives and Requirements

Similar to agricultural remote sensing, the emphasis to date on mineral resources has been target identification and local mapping from aircraft and spacecraft to prepare inventories, determine the spectral signatures of surficial geology, observe such geological hazards and phenomena as volcanic eruptions, and seek indicators of promising ore or petroleum bearing structures. Space photography from Apollo has identified previously unknown fracture patterns, ERTS-1 multispectral imagery has located major fault blocks not previously mapped, infrared imagery has been used from aircraft to discriminate carbonate rock types and geobotanical clues to mineralization are being investigated. Earthquake damage has been studied from both high altitude aircraft and ERTS-1 imagery.

Mineral deposits have various surficial indicators which in some cases may be identified by special remote sensors. In the case of the Shuttle Sortie, a major contribution will be better geological maps with data obtained from a larger variety of sensors. The Shuttle has a good mapping quality hard film return capability. Such films will have good use for geological structure analysis. Important geological studies would include determining the optimum use of photography, radar, infrared and passive microwave imagery in determining clues to mineralization patterns. Microwave instrumentation will be important on the Sortie missions, passive microwave because of the larger antenna sizes required, active microwave because of the power and data processing requirements. Although the primary indicators of mineralization are related to the symmetry or geometry of geological features, apparent anomalies and regional trends, other indicators which may well be identified by the multispectral approach would include geochemical patterns, changes in vegetation cover, and other secondary guides. Radar techniques and thermal infrared should be particularly pertinent to these studies. Cloud-free photography and multisensor imagery once per season per generation of instrument is considered sufficient once thermal, spectral and photographic data may be used to identify and discriminate economic geology targets.

Although geological disaster assessment and monitoring are apt to be more closely associated with contingency mode functions than to the research mission mode, surveillance and advance warning studies of potential hazardous events are a promising role. These include detecting thermal anomalies,monitoring crustal movements and instrumented fault zones,and assessing the possible warnings of destructive events. Photography, multispectral imagery and imaging radar and microwaves are required to implement such research, along with instrumentation to receive in situ data and to compact multispectral sensor data into quickly usable information. Inasmuch as this amount of instrumentation is heavy and bulky, and has large power requirements, initial research in this area might conveniently be done on Shuttle Sortie missions. A promising aspect of the Sortie is the ability to control and vary illumination conditions. Repeated looks at the same scene make feasible the study of thermal inertia in rocks and the study of bi-directional reflectance.

Current suggestions that gimballed mapping quality cameras be mounted on the Sortie orbiter for every mission, where a payload weight accommodation is possible, need further study. These studies could determine the type and extent of photographic

coverage from typical Sortie mission models for disciplines other than earth resources, and also conflicts in pointing and viewing conditions, if any, in the gimballed mode. Also, questions regarding the change in scale and overlap during non-circular orbits, ephemeris correlation and identification of users of such products could be studied further.

3. Geography and Land Use

a. Capabilities

- Topographic and thematic mapping for inventories of physical, cultural and economic resource patterns.
- Land use mapping and monitoring of changes for land use evaluation and assignment, and long-term regional management and planning.
- Inventory of population distribution as related to resource use and conservation, communications and services, rural and urban planning.

b. User Objectives and Requirements

Major sensing applications to geography has included monitoring of land use changes, thematic mapping, and identifying topographic and cultural features. Techniques like optical density slicing have been employed for soil, snow and vegetation mapping. A number of urban areas have been studied from aircraft and ERTS-1 satellite for census correlation and land use studies and were undertaken over pre-selected areas as a basis for computer modeling. To date, the instrumentation has been largely the metric camera and the multispectral imager. ERTS-1 multispectral imagery has proved to be usable for thematic mapping, and land use change detection. Of potential interest is a manned Sortie mission, where the mission specialist would undertake such visual studies as updating portions of the National Atlas or maps of rapidly changing regions. Such experiments would be useful where man's capabilities to recognize certain phenomena under known conditions could be documented and supplemented by photography where necessary.

The study of population patterns require detailed coverage of both urban and suburban settlements, the definition of land use areas, their relation to water and power resources, communication and transportation routes and available land resources. Problems related to multisensor mapping include the development of high resolution cameras, scanners, recorders and on-board film processors. Characteristic land

forms, surface materials, water and power resources need be identified for the purpose of defining such elements of economic geography as suitable for industrial sites, physiographic restrictions or advantages for land use, and transportation routes.

The operational satellites may be able to provide some of these factors, but it is likely that for urban suburban analyses, one would require higher spatial resolution. If only a few cities were important for such analyses, these could be performed using aircraft alone. But global urbanization patterns and land use changes surrounding the cities pose research problems which might be conveniently studied on a Sortie mission. Urban studies could also be combined with other geographic areas, such as harbor traffic and transportation route studies, for a given Sortie mission and utilizing an observation telescope and related sensor systems.

Although it is still a research problem, in many cities the structural patterns related to industry, housing and business districts etc., are regular enough that spatial frequency filtering techniques might be suitable for analyses of such data as acquired from above mentioned (geographic) Sortie missions. If the analysis techniques advance rapidly, it may be possible to generate maps showing only housing areas or only highways for a given urban area because these translate into separate spatial frequencies (sizes) which can be filtered in the electronic domain. Pattern recognition techniques can also be helpful in generating such thematic maps and such information would be of considerable interest for city planning for large cities.

4. Water Resources

a. Capabilities

- Identify and inventory fresh water sources for optimum water supply management. (Includes monitoring of watersheds, lakes, rivers, and ground water features for industrial, agricultural and household use.)

- Snow and ice mapping and monitoring of melt rates for flood forecasting and predicting available water supply

b. User Objectives and Requirements

Similar to the discipline of geography, water resource studies to date have been largely from aircraft and at the levels of mapping and monitoring. Studies have emphasized such information as is generally pertinent to the conservation of

water for municipal use and irrigation, such as monitoring snowpack, drainage basins and estuaries. Photography and multispectral imagery can help delineate effluents (biological and chemical) for pollution studies. The near-infrared imagery such as from ERTS-1 has been recently applied to snow line mapping. Research is in progress on the microwave sensing of snow and ice. Soil moisture measurements have been made using multifrequency microwave. Radiometric measurements have been undertaken to measure chlorophyll in water and to relate the data to lake eutrophication. Satellite multispectral imagery has provided information on drainage lines, flood patterns, snow lines, river and bay pollution, water depths, coastal currents, and some evidences of coastal sedimentation.

Instrumentation which needs further development includes infrared and microwave scanners, radar imagers, and multispectral photography.

Pertinent applications to water resource monitoring includes seasonal inventories of river basins, snow and ice accumulations and melting patterns and possible studies of ground water discharge. Use of such information will be valuable to flood control, reservoir management, the allocation of water to agricultural use and the assignment of hydroelectric power schedules.

Sortie mode missions could provide seasonal and quarterly overflight observations, transmit real-time data to the ground in instances of flood damage assessment or flood warnings, permit the evaluation of a variety of instruments and techniques with drastically reduced restraints on payload or power, and assist in determining the feasibility of sensing techniques in a variety of situations presenting a broad range of spatial and spectral requirements.

5. Marine Resources

a. Capabilities

- Improve ship routing by measurement of sea state, detection of hazards, monitoring sea ice
- Improve fishing productivity by locating cold water upwellings, biologically rich areas, and optimum thermal conditions

b. User Objectives and Requirements

Remote sensing of marine resources from aircraft and ERTS-1 satellite has been largely at the level of mapping and monitoring. Specific studies have identified

pollutants, observed coastal processes and located biologically rich areas. Sea ice surveillance has been undertaken from Nimbus, TIROS, ITOS and other satellites. Computer studies have indicated the relationship between surface wind fields and water surface reflectance. ERTS-1 experiments at the mapping level include measuring sea surface temperature patterns, water color, and observing some time variant phenomena with sequential orbital imagery.

The instrumentation needed for oceanographic sensing studies includes multispectral infrared and microwave scanners, radar image metric cameras, a data system supported by computers, recorders, and display instruments and a multi-spectral ocean color sensor. Primary analysis would be on board the Shuttle. Remote readout of buoys and the use of supporting aircraft would be needed.

Pertinent applications would include establishing techniques for sensing fish distribution and migration as related to fish productivity and food resources. Understanding ocean current and its physical structure will aid in ship routing, monitoring sedimentation and erosion and will effect coastal engineering and construction.

Generally only those areas will be investigated where information is required in more detail than is available from automated satellite. These could include coastal areas, offshore exploration areas, fishing areas, etc. The supplementing information from the Sortie would be to provide more frequent coverage at predictable times, at lower altitudes, and with special sensors.

There is a strong need for a space platform where a 3-10 meter size microwave antenna could be deployed. The Shuttle Sortie studies are a candidate for R&D leading to operational systems employing such large arrays. Instead of one large single dish, if synthetic aperture radars are used, then the data rates are so high from such systems that on-board processing would be necessary, and hence the Sortie mode would be particularly suited. A high-resolution, all-weather radar system on a Shuttle would be most useful to marine applications.

Sea ice mapping and polar ice mapping are two important areas. In any polar mission of the Sortie, these data could be acquired, and a considerable fraction of the polar ice caps could be surveyed in short missions of a few days. One significant result from the ERTS has been the ability to map ice/water boundaries, melting ice and puddles of water on ice using reflective infrared. The thickness of the water

layer over ice gives an indication of the surface temperature. ERTS observations indicate that the polar ice has more openings than thought before which provides for enormous additional energy exchange between the oceans and the atmosphere. This might lead to a better understanding of the polar climate and in some seasons might be aided by Shuttle Sortie observations, since the weather often seems to change over the poles every three to four days.

What problems the passive microwave sensors will be able to solve is still an open question. The L (~1 GHz) and C (~10 GHz) band systems could be used to study sea surface salinity and temperature and the sizes of antennae could be reduced somewhat by going to a lower Sortie orbit.

6. Environment

a. Capabilities

- Monitor air and water pollution sources, concentrations and dispersion patterns and other natural or man-made external elements which degrade the environment
- Assessment or verification of ecological models for determining productivity factors, and the impact of stress on resource and environmental management

b. User Objectives and Requirements

The remote sensing of the environment has largely been directed at the monitoring of pollution and the correlation of environmental degradation with matters of public health and epidemiology. Signatures have been established for various environmental indices associated with pollution and stress. The data has been obtained principally from aircraft such as the use of aerial photography to identify plant communities related to mosquito heeding areas, and the study of the habitat of the vector of Venezuelan equine encephalitis.

Future environmental considerations will include fisheries ecology, mine waters and mining, stress due to agricultural chemicals, urban debris, effluents, and the effects of pollutants on water resource use. A primary requirement is to collect data from in situ stations capable of identifying various chemical and physical parameters in municipal water management. Important sensors which are needed to implement such a program would include metric cameras, multispectral

scanners, ultraviolet radiometer, observation telescope with high spatial resolution and data collection and recording equipment. Environmental and resource management requires consideration of the sources and distribution mechanisms of pollution and the relationship of industrial expansion to the production of such debris and effluents. Management will also require information for land use planning, resource inventories and the pressures of population and engineering needs.

The Army Corps of Engineers would like to have the capability of assessing storm damage under all weather conditions in which microwave sensors from a Shuttle Sortie could prove extremely useful. Because of current weight, power and other requirements, they could be used on the Sortie mode. They would be able to monitor ice in the navigation channels of the Great Lakes, ocean areas, and on the north slopes of the continents.

The Sortie mode might also be useful for periodic monitoring of such a project as land dispersal of waste materials. Several large sites have been selected for waste dispersal throughout the U.S. land area. The feasibility of this depends upon knowledge of soil permiability, saturation with a given chemical and seepage rates. Sometimes diversions might have to be made if these parameters show adverse effects on surrounding land and water distribution. Periodic observations from Sortie missions would be helpful.

Another important application is the ability to measure wave direction. This is an important problem for which remote sensing techniques needs to be explored. The knowledge of such parameters would assist in determining factors in beach erosion and waste dispersal. This could constitute an R&D problem for the Sortie.

D. CONTINGENCY MISSIONS

In addition to the Earth Resource Laboratory Missions, there are categories of ERS contingency missions for which the Sortie mode is suitable. Contingency missions make possible (near - or) real-time monitoring of certain widespread or sudden classes of regional stress or natural catastrophes. Sortie modules suitable as stand-by items for contingency missions would necessarily have capabilities to monitor a wide variety of earth surface conditions and the operators of such modules

would need to be trained in the basics of many disciplines. In the case of the short term operational laboratory missions (below) the Shuttle would be manned by Principal Investigators or similarly qualified scientists or developmental engineers.

The following are examples of events which may be addressed by contingency Sorties in those cases where the mission might not be suited to aircraft:

<u>Catastrophic events:</u>

Monitoring or assessing damage or changes due to:

tidal waves
floods
hurricanes (beaches and inland)
tornadoes
blizzards
volcanic eruption and lava flow
mud flow
land slides
earthquake

Monitoring regional events of public health or welfare nature:

fire
insect infestation
crop disease
epidemics
red tides
breaks in dams, levies

Others:

location of downed aircraft, other rescue missions
establishing transportation route in areas of fire, flooding, storms
crises of water supply, utility failures
location of derelict, floe ice
monitor air and water pollution crises

Contingency missions being on call for emergencies or catastrophic events, should not be emphasized as a component of shuttle sortie planning. Each such mission would be unique, complicated and relatively expensive (i.e., at least \$5M) and might be required to satisfy several diverse objectives. Only under the most demanding circumstances could Sortie use in this mode be justified vis-a-vis to an aircraft mission.

E. EXAMPLES OF APPLICATIONS PERTINENT TO SORTIE MODE

Unmanned satellites such as ERTS are fully capable of obtaining maps and of providing repetitive monitoring data. The Space Shuttle, however, with relatively low cost for its great flexibility is ideal for research and development of instruments and techniques and for short term operational missions which require an investigator. The extent to which Shuttle missions can supplement automated missions depends largely on the capability to select orbital parameters and on effective use of mission specialists.

It is premature to estimate the economy or technical advantages of earth resource sensing from a Sortie mission without an overall estimate of the problems; however, man can be a real time observer and experimenter with breadboard phase instrumentation. The investigator provides flexibility in the use of on-board systems that is often not otherwise possible; also, there are circumstances or opportunities where there will be an advantage in on-board human judgement.

The Sortie mode will permit scientists from various earth resource disciplines to participate in target selection and sensor development on short duration missions. The capability of carrying a large payload will permit sensing over the entire pertinent electromagnetic spectrum, will allow intercomparison of several types of sensors by the investigator and will tend to assure the reliability of instrument performance. Instrumentation can range from experimental models under development to proven equipment representative of best available technology. It would appear that in the early phases in any application, it would be wise to limit sophistication.

Investigator involvement may, in early phases of earth resources sensing also consist of developing specifications for future automated missions. In the instances of those disciplines where man has a unique role as investigator, such as the search for indicators of mineralization or for evidence of earthquake damage, the mission specialist improves reliability, selects targets on conceptual bases, makes reasoned selections as to the data processes to use and matches the optimum sensor techniques to the characteristics of the target or where unforeseen contingencies are encountered.

Table 6 indicates some examples of applications which are pertinent to Space Shuttle Sortie mode limitations and capabilities. Some of these items, such as the canopy model, the atmospheric model, and all weather damage assessment capability are treated in detail in subsequent chapters.

EXAMPLES OF APPLICATIONS PERTINENT TO SORTIE MODE

- DETECT VEGETATION STRESS AND ASSESS DAMAGE (DUE TO HIGH SPATIAL RESOLUTION, SUN ANGLE/LOOK ANGLE VARIABILITY AND LAUNCH FLEXIBILITY AT CRITICAL PERIODS IN GROWING SEASON)

- DEVELOP CAPABILITY FOR CROP YIELD/STRESS DETERMINATION GLOBALLY

  -- CANOPY MODEL (S) (SEE CHAPTER V)
  -- ATMOSPHERIC MODEL (S) (SEE CHAPTER VI)

- MONITOR POLLUTION SOURCES AND DISPERSION PATTERNS (DUE TO ABILITY TO CARRY SPECIAL INSTRUMENTS AND CHOICE OF ORBIT TO VIEW AREA AT LEAST TWICE DAILY)

- ALL WEATHER DAMAGE ASSESSMENT CAPABILITY (MICROWAVE SENSORS AND BROAD AREA COVERAGE), E. G., FLOOD AND RAIN DAMAGE ASSESSMENT (GLOBAL CAPABILITY), SHORT RESPONSE TIME, (DEVELOPING COUNTRIES DO NOT HAVE AIRCRAFT, INSTRUMENTS OR COMMUNICATIONS SYSTEMS); LARGE AREAS OFTEN GET AFFECTED (SEE CHAPTER VII)

- TARGETS OF OPPORTUNITY (EARTHQUAKES, VOLCANOES, ETC.) (PROGRAMMABILITY WHERE RAPID ASSESSMENT IS SUFFICIENT, MISSIONS CAN BE MODIFIED IN NEAR-REAL TIME)

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CHAPTER V

EXAMPLE OF A UNIQUE SORTIE EXPERIMENT: VEGETATIVE CANOPY MODEL -- TEST, VERIFICATION, AND LIMITED OPERATIONAL APPLICATIONS

A. GENERAL

In the present study it is pertinent and important to treat in detail at least one experiment, as an example, which exploits the flexibility and other special characteristics offered by Space Shuttle Sortie missions. These special characteristics of the Sortie were discussed in Chapter III. Here, quantitative estimates, illustrating these, will be presented as these relate to the fulfillment of requirements posed by the resource experiment under consideration. Before plunging into the example it would be desirable to point to some conclusions, which are generally made superficially, regarding the capabilities of a space or aerial system to carry out earth resources surveys.

Present earth observation systems have attempted to optimize the data requirements of many disciplinary areas and thus have limited capabilities for variation of basic parameters such as wavelengths, frequency of coverage, altitude, sun and view angles, and spatial and spectral resolutions. In such relatively "fixed" systems one cannot study the full range of phenomena which might be observable from space or aerial platforms. The Space Shuttle Sortie Mode, because of its flexibility and programmability, offers an opportunity to study those phenomena which may not be optimally (or at all) observable with the relatively "fixed" systems. Thus, from among the total candidate R&D areas, in all natural and renewable resources, one can begin to examine those which are significant and yet require special conditions which cannot be met by "fixed" systems. The simplistic attitude in the past has been to label a system inadequate for the study of a resource phenomenon if in the first attempt only the phenomenon cannot be observed or detected. A more appropriate course of action should be to first develop a basic understanding of the resource phenomenon itself, especially as it varies when viewed remotely under different conditions. As such understanding is developed, one begins to get an insight into a system which can optimize the observation of the phenomenon under

consideration. Thus, initially, a considerable amount of R&D is required, using a flexible system such as the Shuttle Sortie. If the problem is economically significant, it may warrant a suitable tailored remote sensing system (satellite, etc.) for operational applications and routine monitoring of the phenomenon under consideration.

B. VEGETATIVE CANOPY MODEL

One such example which we have chosen in this study has been the study of use of Shuttle Sortie missions for orbital tests/verifications of vegetative canopy models and their limited operational use in the Shuttle Sortie mode. Vegetative canopies form a large class of agriculture and forestry applications and there is considerable economic significance to their monitoring and disease detection. (See Table 7)

Plant diseases and stress have tremendous global economic impact. It is not unusual that every year a large region somewhere on this earth gets affected with pests and drought conditions. An assessment of resulting damage or implementation of preventive measures depends upon the understanding and early detection of such effects. The economic effects on the affected area might be quite severe and may in many cases also affect U. S. economic interests. The obvious question then arises as to whether space platforms can be used to detect plant stress and disease at an early stage. The answer, even intuitively, depends partly upon the flexibility and complexity of such a platform. It is likely that some of these phenomena may be observable in the data from the first generation operational earth resources satellite systems. However, the variety of the types of crop/plant phenomena is so large that any one type of fixed operational system is not likely to optimize such observations for all possible plant disease phenomena of interest.

The variety of agricultural practices within the U. S. and globally necessitate that a basic understanding of crop and tree canopies and the radiation reflected by them be developed under different stages of growth and geographical conditions so as to define observable parameters and conditions. It is clear, if one ponders slightly, from the variety of such phenomena globally that one "fixed" viewing platform will not be sufficient to do the task. Thus, one needs flexible systems for observing the canopies and the Sortie obviously forms a candidate for consideration in those cases where areas covered are large, the sites to be covered are distributed over large areas, aerial observations have to be extended, etc.

ORBITAL TEST/VERIFICATION AND OPERATIONAL APPLICATIONS OF A VEGETATIVE CANOPY MODEL

MOTIVATION

- PLANT DISEASE/STRESS HAS GLOBAL ECONOMIC SIGNIFICANCE
- ANNUAL EFFECTS IN LARGE AREAS OF WORLD
- MIGHT AFFECT U.S. AGRICULTURE AND ECONOMY
- CANOPY MODEL CAN FACILITATE EXTENSION OF PRELIMINARY U.S. CLASSIFICATION RESULTS TO OTHER U.S. AND GLOBAL PROBLEMS

DISCUSSION

- LARGE VARIETY OF PLANT PHENOMENA/STRESS, GROWING PRACTICES AND CRITICAL PERIODS OF INFESTATIONS
- A SINGLE AUTOMATED SATELLITE NOT LIKELY TO MEET ALL SPATIAL, SPECTRAL AND VIEWING REQUIREMENTS
- VEGETATIVE CANOPY MODEL -- REFERENCE G.H. SUITS, UNIVERSITY OF MICHIGAN WILLOW RUN LABORATORIES (ERIM)
- MODELS HELP STUDY CAUSE-EFFECT RELATIONSHIP (EVEN THOUGH SOMETIMES NON-UNIQUELY)
- EXPLORE THE MATCHING OF FLEXIBILITY (PROGRAMMABILITY) OF SHUTTLE SORTIE MISSIONS WITH THE OBSERVATIONAL REQUIREMENTS OF THE MODEL FOR OBSERVING PARTICULAR PHENOMENA

could generally be characterized by botanists and agricultural scientists from ground measurements of the canopy conditions. Sometimes a detected effect may become incorrectly identifiable with a stress/disease condition unless a basic understanding of the cause effect relationship is developed. Thus, one would hope to acquire an understanding of a plant disease/stress situation in addition to being able to differentiate disease/stress in remotely sensed data.

Therefore, these techniques, if combined with a physical model, will help understand the phenomenon. One such physical model has been developed by Dr. G. H. Suits of the University of Michigan's Willow Run Laboratories (now Environmental Research Institute of Michigan) (References 1, 4). This physical model gives the directional reflectance of a vegetative canopy by utilizing radiation balance principles. Table 8 summarizes the relevance of such a model to the Sortie mode.

The relevance of the model to the Shuttle Sortie case is two-fold. First, the Shuttle can be effectively used to verify or field test the validity of the model as far as application from space is concerned, even though the ground and aircraft tests verifying the model have been performed by the time the Sortie flights begin. The reasons are connected with issues of extension of recognition techniques to larger areas (i.e., from space altitudes) and the atmospheric effects which will be discussed in Chapter VI. The flexibility due to orbit instrumentation and altitude selection capability of the Sortie mode may allow field tests/verifications of such a model without the commitment to launch a typical fixed sensor -- fixed orbit-automated satellite system. Secondly, the Sortie can be used in a limited operational mode to gather plant stress/disease data during those critical periods (and only over potentially vulnerable or affected areas) as predicted by the model once its validity and limits of validity have been established. In these periods, automated operational systems may not have the desired frequency of coverage or viewing conditions. A brief description of the model and its applicability to the Sortie are given below, and will hopefully illustrate those two uses of the Sortie mode for canopy model application.

The model predicts the directional reflectance of the canopy based upon representative sample measurements of geometrical and spectral properties of each component of the canopy, together with measurements of plant density per unit area. These measurements are performed in a laboratory experiment in which different stages of growth of the crop are recorded and disease/stress are introduced at

DESCRIPTION OF THE MODEL

- RELEVANCE TO SORTIE :

  1. SPACE TESTS/VERIFICATION NEEDED BEFORE USE. AIRCRAFT TESTS NOT SUFFICIENT -- SYNOPTIC AND ATMOSPHERIC DIFFERENCES

  2. LIMITED OPERATIONAL USE OF SORTIE AFTER MODEL VERIFICATION PREFERRED INSTEAD OF DESIGNING AN AUTOMATED OPERATIONAL SYSTEM (THIS MIGHT REDUCE COSTS AND OPTIMIZE COVERAGE/VIEWING PARAMETERS)

- RADIATION BALANCE IN MULTIPLE LAYER CANOPY (EXAMPLE: CORN, 2 LAYERS AND BARE SOIL)

INPUT	MODEL	OUTPUT
COMPONENT (LEAF, STALK, ETC.) MEASUREMENTS ON HORIZONTAL AND VERTICAL AREA, DIFFUSE SPECTRAL REFLECTANCE (ρ) AND TRANSMITTANCE (τ) PLANTING DENSITY/UNIT AREA SOLAR SPECULAR FLUX ABOVE THE CANOPY SUN ANGLES AND VIEW ANGLES	→ CALCULATIONS →	NON-LAMBERTIAN COMPOSITE DIRECTIONAL (SPECTRAL) REFLECTANCE OF THE CANOPY (ρ CAN) AS FUNCTION OF SOLAR AND VIEW ANGLES

various stages of growth of the crop. For the case of a corn crop, the measurements could include horizontal and vertical leaf area measurements and similar measurements for the stalk, kernel and the tassel components. Multiple layers can be assumed for this model as shown in Figure 3, although its recent applications have only been made to two layers and bare soil boundary situation. Reflection and transmission spectra of the leaves and other components in the wavelength region of interest (in the case less than 3-4 μ m) are also obtained in the laboratory. It is assumed in the model that the components are all Lambertian or diffuse reflectors so that the radiance from them is independent of the direction of observation. However, since the geometry of the canopy (spacing and density of plants and component area projections in horizontal and vertical planes) is retained in the model, the overall reflectance of the canopy is non-Lambertian, i.e., is dependent on the direction of look. The reflectance of the vegetative canopy is thus a function of the sun angle and the observation angle, namely θ and ϕ of Figure 3. Therefore, one hopes to illustrate that different types of stress/disease conditions are distinguishable in different viewing conditions, a situation in which programmability of the sortie orbit and viewing angles is likely to prove very useful.

The components of the canopy are assumed to be randomly distributed and homogeneously mixed in horizontal layers and their horizontal and the two orthogonal vertical projections (optical cross sections) are replaced by equivalent diffuse panels. The purpose of the model is to trace and separate the geometric or spectral changes, which are observed in the remotely sensed canopy due to a particular stress/disease situation. The drought or blight might lead to drooping of leaves, thus reducing horizontal projections of leaves and increasing the soil boundary visibility. A unique relationship between drooping and disease might be very difficult to obtain but accompanied spectral changes (yellow leaves in case of drought, brown leaves for blight or rust, etc.) might help narrow the realm of possible diseases. It is to be pointed again that one would like to utilize as much available data on the conditions prevailing in the area of interest (i.e., ground truth) as is conveniently possible for a given problem, and thus remote and ground activities ought not to be considered mutually totally exclusive.

The incident flux (from the sun and the sky) at the canopy layer is assumed to be specular. This would almost be the case if there were no atmospheric effects. Thus, the first interception of the radiation by any canopy element converts the radiation to diffuse part and it is reflected, absorbed or transmitted diffusely.

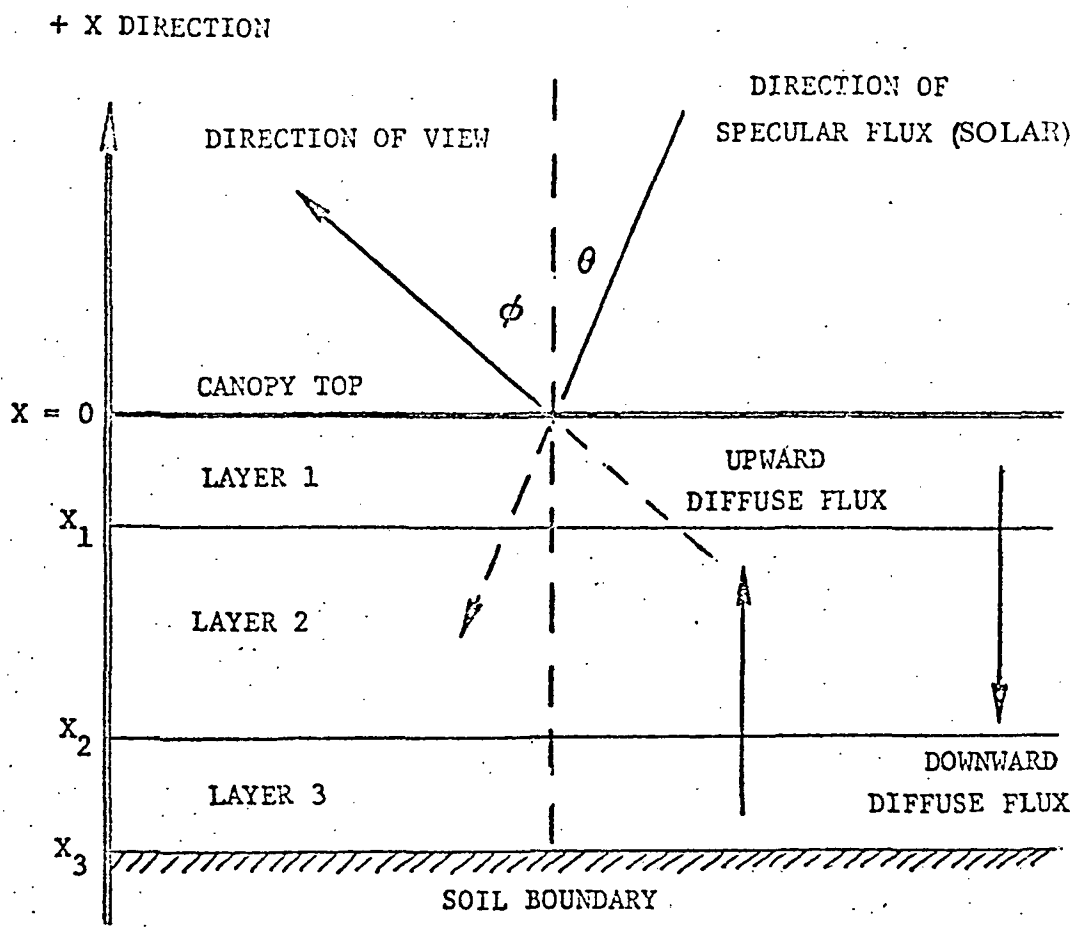

FIGURE 3. IDEALIZED LAYER STRUCTURE OF A CANOPY. Each layer represents a uniform mixture of biological elements normally found at that level in the vegetative canopy. (Reference Suits, G. H., Journal of Remote Sensing of Environment, 2, 117, 1972)

Conservation of energy yields absorption of the hemispherical (diffuse) reflectance (ρ) and transmittance (τ) are known for the elements from laboratory measurements. The specular flux from the sun is assumed to be converted into totally diffuse flux once it hits any component of the canopy. It is divided into upward and downward diffuse flux for the radiation balance calculations. Boundary conditions at the various layers and at the soil layer allow the computation of spectral flux density (both diffuse and specular, and upward and downward) at any point in the canopy as a function of σ_h, σ_ν, H_h, H_ν, τ, ρ, κ, λ, ϕ and the angle θ;
where

σ_h = average horizontal plane projection of a componet.
σ_ν = average vertical plane projection of a component.
H_h = number of horizontal projections/unit volumes.
H_ν = number of vertical projections/unit volumes

and

θ = polar angle for incident specular flux.

The next step in the Suits model is to compute the infinitesimal layer contribution to the radiance of the canopy. Naturally, the overall radiance L (λ, ϕ) is the sum of contributions from each layer and the soil boundary and depends upon the direction of look (polar angle ϕ, Figure 3), and is the quantity measured by a sensor in the absence of the atmosphere. In computing the radiance outside the layer, one has to allow for the exponential attentuation through the layer as well as obscuration (attenuation) due to other layers preceding it.

Thus, the radiation incident on the top and traversing through various layers of the canopy (i.e., spectral density, E (λ, ϕ) depends upon the solar illumination angle (polar angle θ) and upon the attenuation along the line of sight (k, the attenuation coefficient is also a function of the tangent of θ). Similarly, the radiance received by a sensor depends upon the polar angle of view, θ through trigometric functions). The resulting reflectance of the canopy, which is essentially the radiance divided by the incident downward flux density at the top of the canopy, has been computed by Suits (Reference 1) for the case of a two layer corn canopy with bare soil bottom boundary. The contributions to the reflectance are thus traceable to the component reflectance, transmittance, geometric cross sections, and the angles of observation and illumination. These relate to the classical leaf area indices as defined by agronomists.

The soil was assumed in the Suits model to have a uniform spectral reflectance of 10%, and the sun angle θ was taken as 45°. The resulting reflectance of the canopy for various polar viewing angles ϕ is shown in Figure 4. One can see that the radiance received by the sensor will depend heavily on the viewing angle. The reflectance changes are similarly strong functions of the age of the crop and the solar illumination angle.

For the visible and the near infrared portion of the spectrum the reflectance for healthy and stressed corn canopies with same planting density, age, etc. are shown in Figures 4 and 5. It can be seen that the leaf droop increases the non-Lambertian character of the canopy. Thus, at the vertical view looking straight down the reflectance of a stressed corn canopy is much less than that of a healthy one provided other parameters are the same and, furthermore, that the ratio of the reflectance at nadir view angle to that at $\phi = 75°$ is larger for a healthy canopy than that for a stressed one as can be seen from Table 9 for 1 μm wavelength and for a sun angle of 45°. This fractional change should be distinguishable by spectrometer on board. The model not only predicts the variation with the view angle, but alto indicates that largest reflectance changes with view angle correspond to 0.8 - 1.2 μm region for corn. The selection of this band for observing corn at this stage of growth depends upon other factors as well such as the flux incident in this band, atmospheric effects and the detector/filter sensitivities in this region of the spectrum.

Similarly, shuttle sortie missions can be planned to take advantage of the observations under different sun illumination conditions. The discussion which follows shortly will illustrate the likely number of passes during a given sortie mission and the likely sun angles observable during those passes. It may be important to vary these parameters in a short time (for example, a week during a growing or harvesting season) for which again the sortie mission programmability appears quite advantageous. The model is illustrated so that one gets a feel for variation of effects under different physical and biological conditions and it is implied that flexibility is the key element which allows observation of the particular stress/disease condition of economic importance out of the variety of such parametric variations for all possible crop/disease permutations and combinations.

C. EXTENSIONS OF THE MODEL

The model has applicability to other crops and vegetation (other than corn) and is being extended by Suits for some of the applications. Other crops such as wheat,

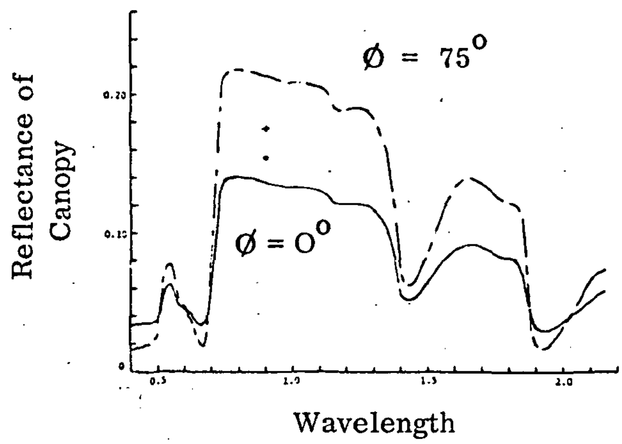

Figure 4. Effect of Viewing Angle (Ø) on Reflectance of an Unstressed Corn Canopy. (Sun angle Θ = 45°.) (Reference Suits, Ibid)

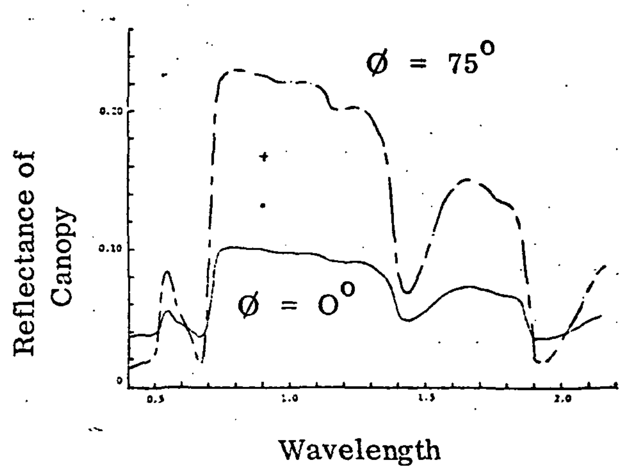

Figure 5. Effect of Viewing Angle (Ø) on Reflectance of a Stressed Corn Canopy. (Reflectance change due to leaf droop; decrease of horizontal with corresponding increase in vertical components increases the non-Lambertian character of the canopy; sun angle Θ = 45°.)

TABLE 9

RESULTS OF MODEL FOR CORN CANOPY (2 LAYER)

GEOMETRY (FIGURE 3), REFLECTANCE FOR HEALTHY CROP (FIGURE 4), REFLECTANCE FOR DISEASED CROP (FIGURE 5), VIEW ANGLE (POLAR) EFFECTS PRONOUNCED AT $\phi = 75°$.

WAVELENGTH 1.0 μm	HEALTHY CORN	STRESSED CORN (LEAF DROOP)
VIEW ANGLE $\phi = 0°$	ρCAN = 0.14	ρCAN = 0.10
$\phi = 75°$	= 0.24	= 0.22
FRACTIONAL CHANGE AS VIEWING ANGLE CHANGES FROM 0° TO 75°	= 0.58	= 0.45

THE PROGRAMMABILITY OF THE SHUTTLE WILL HELP MEET SUCH VIEWING REQUIREMENTS.

which are of great economic importance are now being studied.

Several types of forests can be studied with the help of such a model. These include deciduous, coniferous, multilayered tropical forests and forests under which agriculture takes place. The model is being extended to aqua-canopies, i.e., the canopies under water or such as algae under water or rice under water. For such applications, the model has to account for refraction in water, light scattering by particulates and attenuation. The model has environmental and water quality relevance and has to be tested for deep water situations also. Extensions of the model are summarized in Table 10.

Other models have been also developed in the literature where statistical techniques of random canopy component orientations and effects of skylight including its angular variations have been studied. For the Prairie Region of the U.S. and Canada a model has been developed by Smith and Oliver (Reference 2) in which the canopy components are treated as statistical ensembles in a soil background. Multi-component mixtures are allowed and stochastic structure of canopy is adopted for a Monte Carlo Model. The reflectance in 0.4 and 1.05 μm region for a grass (Bouteloua Gracilis) canopy with one and two layers has been calculated and except for some discrepancies the agreement with observed reflectances has been found.

Other models including multi-stage sampling convex mixtures and energy exchange mechanisms in plants are also being developed (Reference 3).

1. Azimuthal Effects

In addition to the dependence on polar sun and view angles (ϕ, 0), the reflectance of the canopy also depends upon the azimuthal angle (Reference 4). The variation is illustrated in Figure 6 for a stand of bare tree canopy with a snow surface. For this type of tree, it can be seen that the azimuthal effects are most pronounced when the polar angles are large.

2. Requirements From Models

It is clear from the foregoing discussions that the solar illumination and view angle requirements are likely to be different for different crops and under different stages of growth. Even though the preliminary tests of such models may be carried out on the ground or in the aircraft, the applicability of such models to space situations requires a space platform which is flexible, programmable and in which the orbits can be varied from time to time; for R&D efforts the Shuttle Sorties form clear candidates. The problems to be selected for Sortie mission have to be

TABLE 10

EXTENSIONS OF THE MODEL

A. CROPS OTHER THAN CORN (E. G., WHEAT, ETC.)

B. SEVERAL TYPES OF FORESTS (DECIDUOUS, CONIFEROUS, MULTILAYERED TROPICAL FORESTS, FORESTS UNDER WHICH AGRICULTURE TAKES PLACE)

AZIMUTHAL EFFECTS (FIGURE 6) FOR A BARE TREE CANOPY WITH SNOW SURFACE.

C. AQUACANOPIES - RICE UNDER WATER (EARLY STAGE)

- ALGAE IN LAKES

MODEL ACCOUNTS FOR REFRACTION IN WATER.

OTHER MODELS INCLUDING MULTISTAGE SAMPLING AND CONVEX MIXTURE ARE ALSO BEING DEVELOPED.

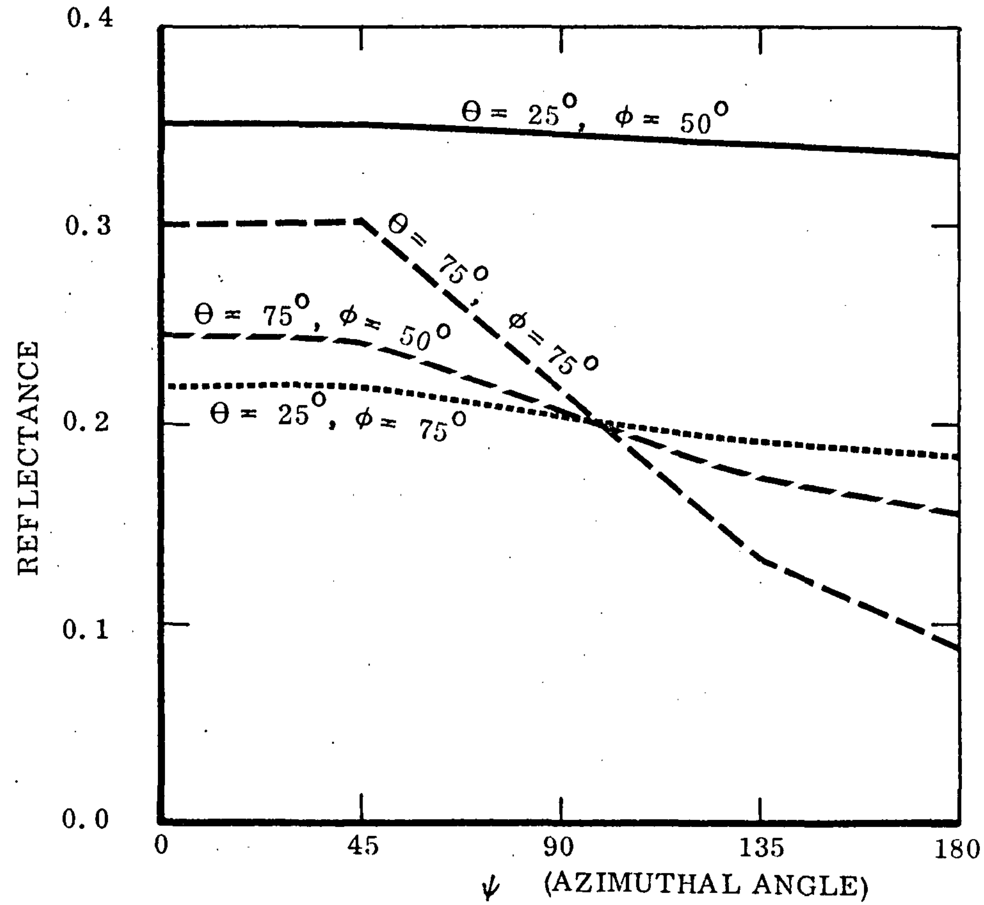

FIGURE 6. Reflectance of a winter deciduous forest for different solar and viewing polar angles (Θ, ϕ) as a function of azimuthal angle (ψ is the azimuthal angle between the solar and view directions).

economically significant to justify launching Sortie missions for them or sharing the cost of the mission with other disciplines. The requirements from models are thus of various types. One may require specific wavelength regions to be observed, specific times in the growing season with a certain frequency of observation, and at specific geographic locations and with certain spatial resolutions. These would narrow the launch windows, altitude and the inclination of the orbit. Further definition of the Sortie orbital parameters will be obtained from the viewing requirements of the model, for example, the solar illumination and viewing angles. In the following we study the matching of the model requirements with the orbital characteristics of the Shuttle. Thus, only two examples are given to show that it is possible to match them.

D. PROCEDURE FOR MATCHING THE SHUTTLE ORBITAL CHARACTERISTICS WITH OBSERVATIONAL REQUIREMENTS FROM MODELS

EXAMPLES (See Table 11)

1. Given the Shuttle orbit, determine the solar elevation angles over a known ground site.

2. Given the illumination requirements from the models, determine the Shuttle orbital parameters for a given duration mission. The problem with respect to earth looking experiments is quite general and numerical solutions can be obtained, but a specific orbit is assumed here which has been dealt by Shapiro (See Reference 5).

The Space Shuttle has diverse capabilities and can be launched into a non-circular orbit, but for simplicity we will illustrate circular orbit case only. Furthermore, as can be seen from Figure 7, the plane of the orbit of the satellite stays relatively fixed in inertial space if there are no significant perturbing forces acting on it. Also any given point on the earth, which is situated at a latitude (ϕ) smaller than the inclination angle (i) of the orbit, passes through the satellite ground track twice per day. Thus, there are two sightings per day (A and B crossings). But in fact, there is precession of the orbit around the earth at a constant rate which depends on the altitude and the inclination of the orbit and is caused due to the oblateness of the earth. The earth's rotation and precession together with altitude and inclination of the orbit determine the rate of change of transit time. A change in transit time at a given site implies change in solar elevation angle. The rate of

TABLE II

PROCEDURE FOR MATCHING SHUTTLE ORBITAL CHARACTERISTICS WITH OBSERVATIONAL REQUIREMENTS FROM MODELS

EXAMPLES

(1) GIVEN THE SHUTTLE ORBIT, DETERMINE THE SOLAR ELEVATION ANGLES OVER A GROUND SITE

(2) GIVEN ILLUMINATION REQUIREMENTS (FROM MODELS, ETC.) DETERMINE THE SHUTTLE ORBITAL PARAMETERS FOR A GIVEN DURATION MISSION (E. G., THIRTY DAYS)

- REFERENCE S. SHAPIRO, BELLCOMM B70-06078, JUNE 1970
  - ASSUME CIRCULAR ORBITS ONLY -- FOR SIMPLICITY, ALTHOUGH SHUTTLE HAS MORE DIVERSE CAPABILITY WHICH OUGHT TO BE CONSIDERED
  - TWO SIGHTINGS/DAY FOR ANY POINT WITH LATITUDE LESS THAN INCLINATION (FIGURE 7)
  - DAILY TRANSIT TIME CHANGES (FIGURE 8) WITH ALTITUDE AND INCLINATION
  - SOLAR ELEVATION ANGLE DEPENDS ON LATITUDE AND LOCAL MEAN TIME (FIGURE 9): DIURNAL VARIATION FOR 30° LATITUDE OVER ONE YEAR)

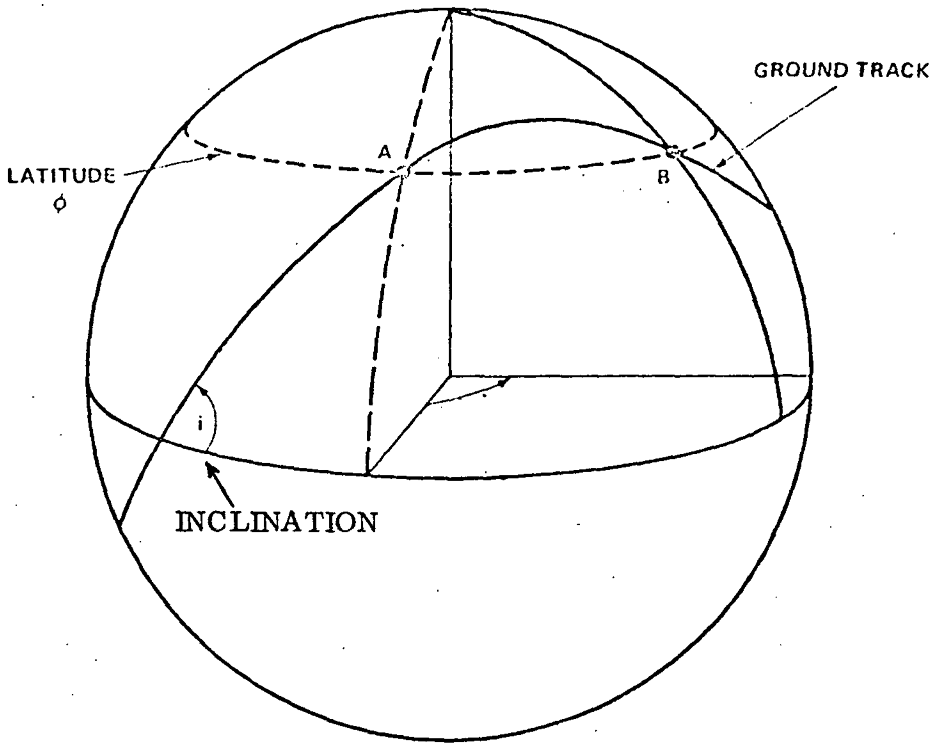

FIGURE 7. GEOMETRY SHOWING TWO SIGHTINGS A AND B PER DAY. (REFERENCE SHAPIRO, IBID)

change of daily transit time in hours/week as function of altitude and inclination of the Shuttle orbit is shown in Figure 8. The solar elevation angle varies in a complicated way as a function of the time of the day through the year and has been calculated by Shapiro (Reference 5) and is shown in Figure 9 for 30° N latitude.

Example 1

If the Space Shuttle in a 250 nm, 50° inclination orbit moving with an increasing lattitude passes over a resource site at latitude 30° N at 1200 hours local mean time on March 31, then how will the solar elevation angle vary at subsequent sightings of the site?

Thus, the crossings (A) in Figure 7 occur at noon and subsequent crossings will occur on a straight line of slope -2.7 hours per week for this orbit as shown in Figure 9 and labelled A beginning at March 31. The other crossings (B) of Figure 7 are shown by lines marked (B) which occur eight hours later (Reference 5) i.e., at 2000 hours. For a 30-day Shuttle Sortie mission the sightings shift at the rate of 2.7 hours/week earlier. Thus, sightings (A) will occur at 1 a.m. local time while sightings (B) will occur at 9 a.m. local time at the end of the thirty day mission. Hence, for a thirty day Sortie, the solar illumination angle for both sightings (A) and (B) will vary from 0° to 50° but the azimuthal angles may be different for these two cases. This is summarized in Table 13.

For a seven day Sortie mission the solar illumination angle will vary from 30° to 50° for sightings (A) and from 0° to 5° for sightings (B). Thus, several sightings can be made and for varying sun angles.

Example 2

The canopy model for a given crop requires solar elevation angle of 10° for observing the effect under consideration for a site at 45° N latitude during a 30-day Sortie mission, what orbit of the Shuttle will be most suitable for this requirement?

The solar elevation angles as function of the local mean time and the date during the year for the site are shown in Figure 10.

Thus, over a 30 day period the tangents, A, B, C, and D are the straight line approximations to the 10° elevation contours for the given site. The slopes for these lines are given in Table 14.

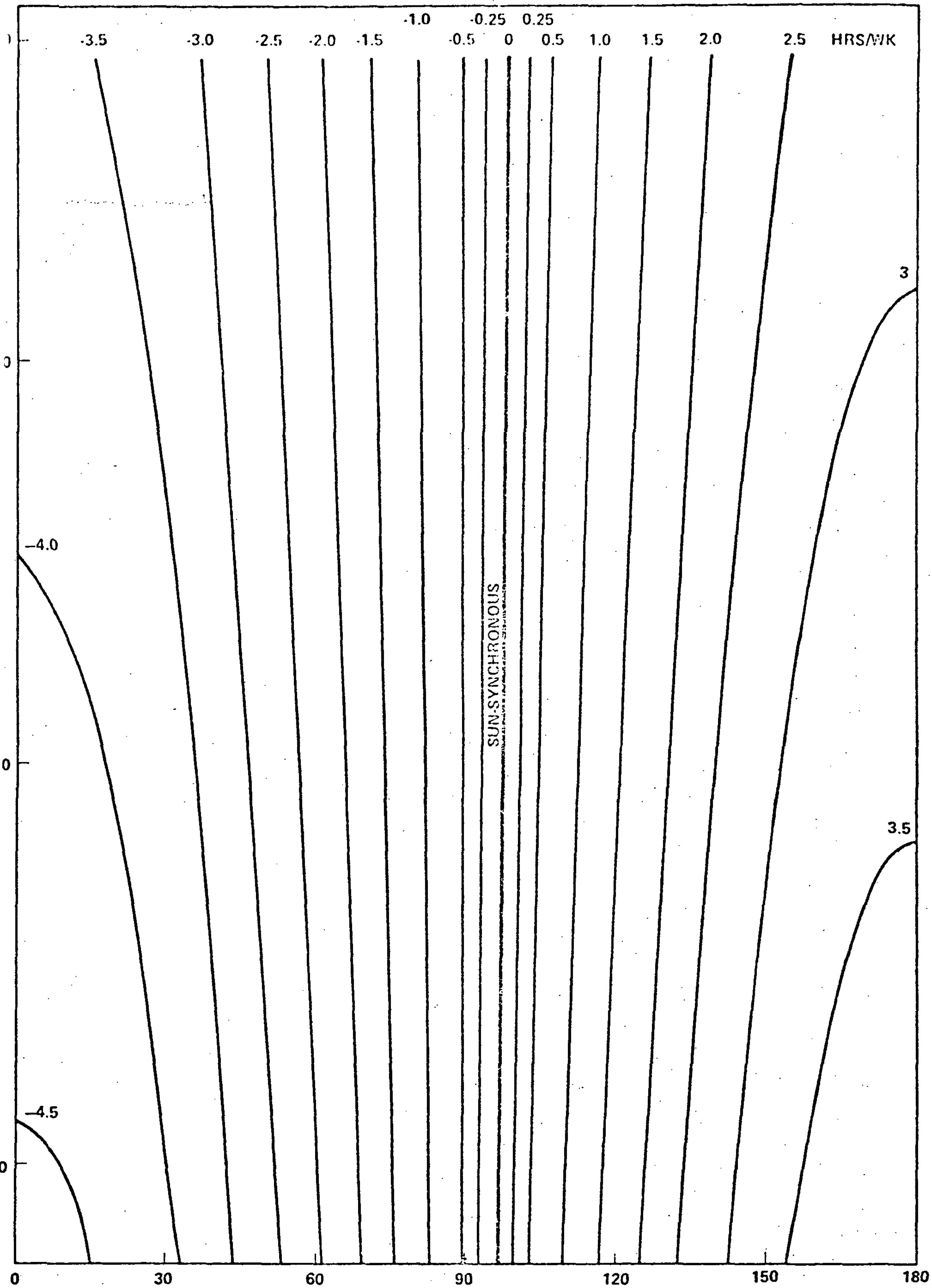

Figure 8. RATE OF CHANGE OF DAILY TRANSIT TIME (HRS./WK.) VS. ALTITUDE AND INCLINATION

(REFERENCE SHAPIRO, IBID)

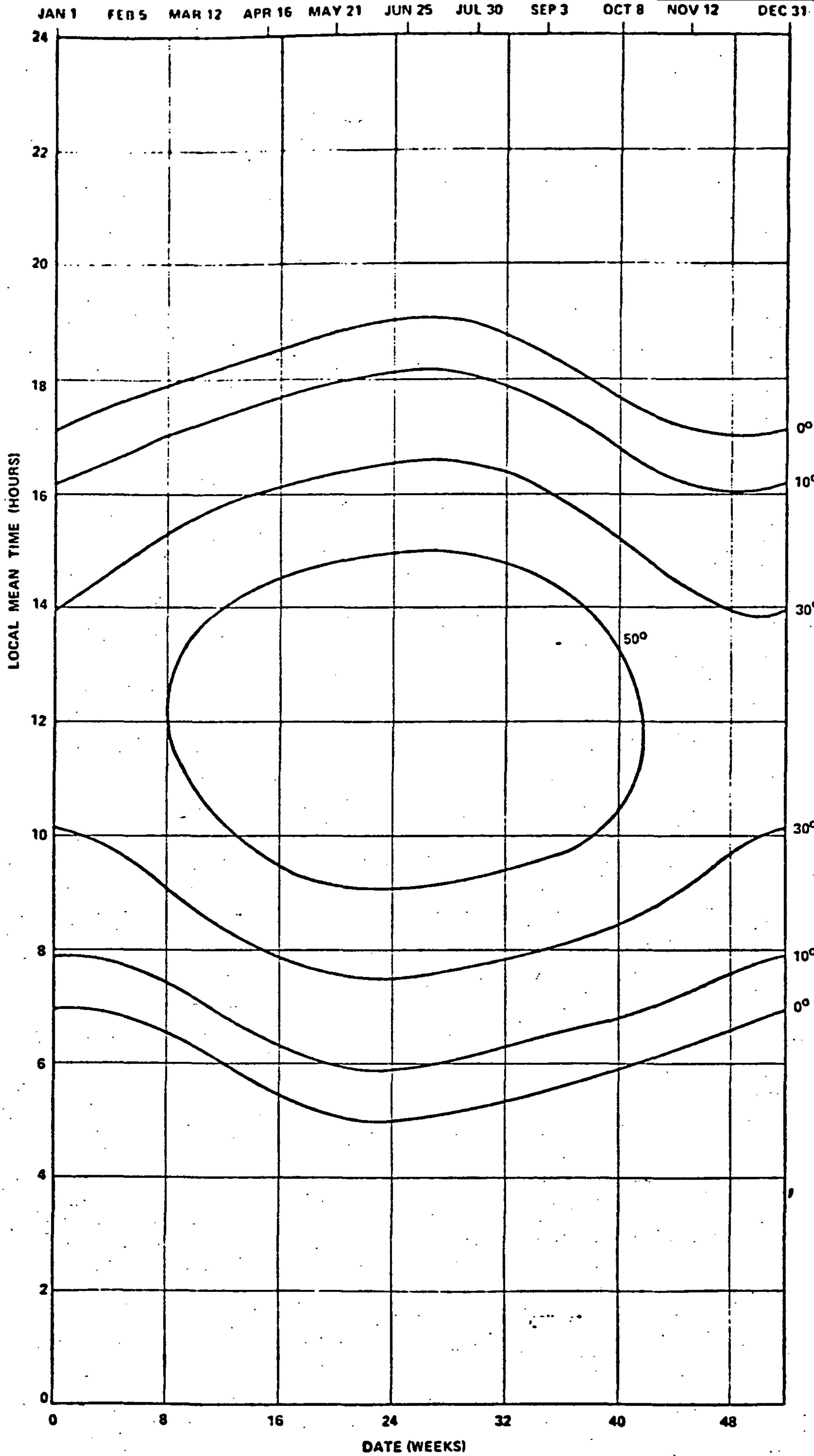

FIGURE 9. DEPENDENCE OF SOLAR INCLINATION ON LOCAL TIME AND LATITUDE (30°) (AFTER SHAPIRO, 1970)

TABLE 12

<u>EXAMPLE 1</u>

- GIVEN SHUTTLE ORBIT: ALT 250 NMI, INCLINATION 50°, TARGET LAT. 30° SHUTTLE OVERFLIGHT AT NOON (A ON FIGURE 7, SUN ELEVATION 50°) ON MARCH 31
- B (SECOND CROSSING) OCCURS AT 8 PM LOCAL TIME (NIGHT) (REFERENCE SHAPIRO, IBID)
- FOR 50° INCL. ORBIT (FIGURE 8) SHUTTLE PASSES 2.7 HRS/WEEK EARLY FOR GIVEN TARGET
- THEREFORE IN 4 WEEKS (30 DAYS) THE LOCAL TIME OF (A) SIGHTING WILL BE 11 HOURS EARLY, I.E., 1 AM LOCAL TIME
- ALSO (B) SIGHTINGS WILL BE 11 HOURS EARLY, I.E., 9 AM LOCAL TIME
- HENCE SUN ELEVATION ANGLE VARIES FROM 50° TO ZERO FOR SET (A) AND (B) SIGHTINGS
- IF THIS WERE A SEVEN DAY SORTIE MISSION, THE LOCAL TIME WOULD BE (NEARLY) 9:30 AM, I.E., SUN ELEVATION OF NEARLY 30° FOR SET (A)
- <u>TOTAL NUMBER OF DAYLIGHT SIGHTINGS</u> NEARLY 42 FOR A 30 DAY MISSION AND 11 FOR A 7 DAY MISSION
- THE <u>SUN ANGLE VARIES</u> FROM O TO 50° FOR A 30 DAY MISSION AND FROM 30° TO 50° AND O-5° FOR A 7 DAY MISSION
- HENCE DIFFERENT SUN ANGLES CAN BE STUDIED

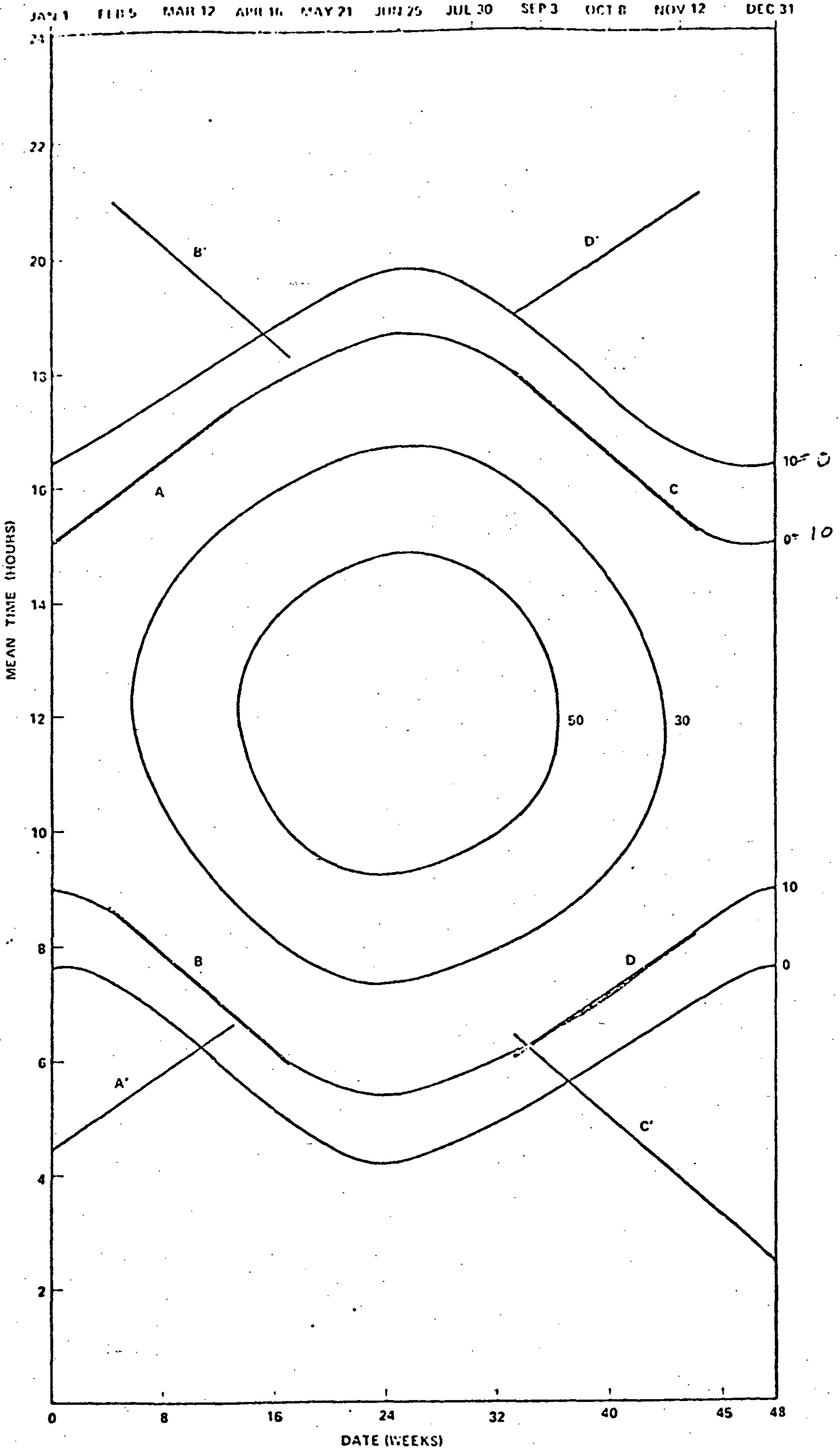

FIGURE 10. CONTOURS OF SOLAR ELEVATION (DEG) VS. LOCAL MEAN TIME FOR LATITUDE 45° N

EXAMPLE 1 (CONTINUED)

GIVEN SHUTTLE ORBIT 250 n. mi., 50^{o} INCLINATION,
1200 NOON MARCH 31 SET A SIGHTING AT 30^{o} LATITUDE

	Number of Passes in Daylight		Range of Solar Elevation Angles *	
	A	B	A	B
7 Day Missions	7	4	$30 - 50^{o}$	$0 - 5^{o}$
30 Day Missions	18	26	$0 - 50^{o}$	$0 - 50^{o}$

* Have different azimuth angles

ORBIT SHIFTS -2.7 HOURS/WEEK IN LOCAL TIME

TABLE 14

ORBITAL PARAMETERS FOR EXAMPLE 2

Slope	Hours/Week	Inclination	Date	Hour
A	+ 0.18	98° - 101°	Jan. 1	1500
B	- 0.21	93° - 95°	Jan. 29	0830
C	- 0.21	93° - 95°	Aug. 20	1800
D	+ 0.16	98° - 100°	Aug. 20	0600

One can go to Figure 9 and get the range of inclination for these slopes and these are also listed in Table 14. The precise value of inclination is determined by the altitude chosen and the requirements posed by other experiments. Any of the four dates and times can be used to determine a suitable launch time because at these dates and times the solar elevation angle is 10° over the site. Similar to Example 1, there are sightings A, B, C, and D which mostly occur in the night, however.

The altitude and field of view of the instrument for getting maximum sightings over this site can be determined by a method prescribed by Shapiro (Reference 6). A half angle of 30° and altitudes in the 260-270 or 360-380 nm range give an observation every 3 or 4 days.

Thus, one can define the orbital parameters of Shuttle Sortie missions which would give frequent sightings under the illumination conditions required by canopy models.

E. SUMMARY OF STUDY OF CANOPY MODELS WITH SORTIE MISSIONS

The Sortie missions can thus be used to develop, test and verify the canopy models. The sun angle (illumination angle) and view angle variations required by the models can be studied suitably with Sortie missions lasting 7 to 30 days. Some instrument variations can be possible during the mission or between the missions to optimize viewing of a particular aspect of canopies. Time criticality requirements -- usually associated with the different stages of growth of crops and with periods during which the crops are susceptible to infestations -- can be met by Sortie missions since the short duration missions can be programmed and have the flexibility. Similarly, repetition of coverage and associated illumination and viewing requirements can be met in order to detect change in the growth stage and vigour of the crops, by launching the sorties in suitable orbits. Atmospheric corrections may be necessary for certain viewing conditions and suitable measurements from orbit can be performed to facilitate the same.

As discussed, in the initial stage of testing the models, the flexibility of the Space Shuttle is likely to prove very useful. Similarly the Shuttle Sortie missions can also be used for limited operational applications of these models; for example, if mission can be shared with other experiments then some routine surveys can be performed. Also for some operations, the development and deployment of an

automated satellite may not be justifiable or may be delayed and the Shuttle Sortie missions can provide the desired data in these situations. The models can also be used for extending applications to large areas though knowledge of the cultivation practices has to be incorporated in such extensions. Overall, therefore, Sorties provide a good way to study and verify the canopy models and their applications to operational situations can lead to large benefits. Table 15 summarizes the canopy model impact.

TABLE 15

SUMMARY OF CANOPY MODEL IMPACT

- VARIATION IN LOOK ANGLE/SUN ANGLES KEY FACTORS IN APPLYING CANOPY MODELS
- TIME CRITICALITY -- WHEN TO OBSERVE IS IMPORTANT (FOR EXAMPLE DURING 2 WEEKS IN GROWING SEASON)
- REPETITIVE COVERAGE AT SAME LOOK/SUN ANGLES COULD HELP DETERMINE CHANGES IN VEGETATIVE VIGOR
- MODELS ALLOW EXTENSION OF APPLICATIONS TO LARGE REGIONS GLOBALLY (KNOWLEDGE OF CULTIVATION PRACTICES REQUIRED)
- MODELS HELP IN MISSION PLANNING AND RESOURCE MANAGEMENT DATA REDUCTION, OPTIMUM WAVELENGTH SELECTION
- ATMOSPHERIC CORRECTIONS MAY OFTEN BE REQUIRED

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CHAPTER VI

ATMOSPHERIC EFFECTS

A. DISCUSSION

In any remote sensing work in Earth Resources, the atmosphere plays an important role. Sensors in aircraft or satellites view the ground through the atmosphere. Not infrequently, the atmosphere itself may be of interest, as in the case of air pollution studies. In any case, the atmosphere quantitatively affects what we see from the ground. Even in the so called atmospheric windows (through which all sensors must look if they are to see the ground at all), the atmosphere is not completely transparent. Further, its effect on ground radiance is different depending on base altitude of terrain, the amount of particulate matter in the atmosphere, distribution of that matter with altitude, and the presence of absorbing constituents.

Because of the effects of the atmosphere, sensors for space use must be designed not considering ground radiance levels, but those levels modified by the atmosphere. This modification was made in the design of both ERTS-1 and Skylab S-192 multispectral scanners, although a limited range of atmospheric effects was probably considered.

With the trend to automatic and hopefully onboard processing of scanner data by computers using spectral signature information, some quantitative knowledge of atmospheric effects is required for reliable processor operation over large areas of terrain to be surveyed.

The Space Shuttle Sortie mode is useful in two ways in connection with the atmospheric effects in the earth resources data:

(1) In the efforts to carry out research and development in order to develop adequate observational parameters and models to correct for the atmospheric effects in the remotely sensed data. One such model that has been developed in this connection for correction to the ERTS-1 data is described later in the section in detail to illustrate the important parameters which affect the reflected radiation as it is viewed from a space or aerial platform.

(2) For the study of the atmospheric constituents and their distribution, with the use of specialized instruments and techniques not generally available on automated meteorological or earth resources satellites.

A study covering some aspects of (2) above has been initiated* with a view to understanding the atmosphere from a scientific standpoint. The emphasis, in this connection on fundamental studies for our purposes is limited to the extent that such studies affect the atmospheric corrections applicable to the remotely sensed data. Thus window regions, edges around the window regions, and the study of constituents and phenomena, as these affect the "visibilities" in the window regions are some examples where studies could help in our understanding of the atmospheric effects on ground radiance reaching the space platforms.

There is a third aspect to the problem that specifically relates to the Shuttle. It concerns the variety of ways in which the atmosphere might enter in the Shuttle-acquired data. In Chapter V, discussion of the Canopy models and the versatility of the Shuttle for different sun and view angle observations were emphasized. The atmospheric effects are likely to be quite varied and different under varying observation conditions. For example, the atmospheric path length variations will be different, depending upon the view angle while the incident solar illumination will be different, depending upon the elevation of the sun. Thus, spectral and total

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* "Preliminary Design Study for an Atmospheric Science Facility", Progress Summary, prepared for NASA, MSC, Houston, Texas, August 1972. Contract NAS9-12255, Martin Marietta Corporation, Denver, Colorado.

attenuations will change. This problem is a bit more involved than in the case of fixed view satellites where some of these aspects do not change and one is concerned with variation of the atmospheric conditions alone. Thus, in (2) above one can use the Shuttle for gathering basic data on the atmosphere as it might affect different viewing conditions. The Space Shuttle-acquired data will be used for classification of resources in addition to other applications. In this situation the atmosphere has to be studied because correcting for it may reduce the classification error/false alarm rates to acceptable levels for a broader range of atmospheric conditions. Table 16 outlines the atmospheric effects influencing remotely sensed earth resource data.

Some areas of the globe are constantly under adverse atmospheric conditions for large parts of the year. These include haze, fog, cloud, sand-storm and rain affected areas. Many of these lie in the tropics. With the help of adequate models it may be possible to extend the classifications to such areas.

This understanding of the atmosphere also has a very important goal, i.e., to correct for the atmosphere automatically in the operational satellites. For this R&D performed on the Sortie missions will help define those parameters which are critical and ought to be measured on the operational satellite so that one obtains atmospherically corrected resource data to the extent possible.

In this Chapter, the nature of known atmospheric effects will first be discussed. Effects on photographic sensors and scanner systems will be detailed. Then model calculations will be presented showing the magnitude of atmospheric effects on the ERTS-1 sensor.

B. ATMOSPHERIC EFFECTS IN DETAIL

What are the effects of atmosphere on radiance signals from the ground? A general equation may be written for the attenuation of ground radiation and the introduction of "path radiance" because of scattering of atmospheric aerosols.

TABLE 16

ATMOSPHERIC EFFECTS IN EARTH RESOURCES DATA

- ATMOSPHERE IS A COMMON FACTOR, ALWAYS INFLUENCING REMOTELY-SENSED DATA FROM AIRCRAFT AND SPACECRAFT
- SHUTTLE SORTIE MODE USEFUL IN TWO WAYS
    - (1) FOR THE R&D NEEDED TO REMOVE ATMOSPHERIC EFFECTS IN THE EARTH RESOURCES DATA (MODEL DESCRIBED BELOW)
    - (2) FOR STUDYING THE ATMOSPHERIC CONSTITUENTS AND THEIR DISTRIBUTION UTILIZING SPECIAL INSTRUMENTS AND TECHNIQUES NOT GENERALLY AVAILABLE ON AUTOMATED METEOROLOGICAL OR ERS SATELLITES (REFER TO ATMOSPHERIC SCIENCE FACILITY STUDY - MSC)
- ATMOSPHERE NOT COMPLETELY TRANSPARENT EVEN IN THE "WINDOWS"
- DESIGN OF AN OPERATIONAL SYSTEM OUGHT TO BE BASED ON RADIANCE AS MODIFIED BY ATMOSPHERE
    - -- TO REDUCE CLASSIFICATION ERROR/FALSE ALARM RATES TO ACCEPTABLE LEVELS FOR A BROADER RANGE OF ATMOSPHERIC CONDITIONS
    - -- TO MAKE TERRAIN CLASSIFICATION FEASIBLE IN SOME CONDITIONS AND WORLD AREAS WHERE IT WOULD NOT OTHERWISE BE SO
- GOAL OF OPERATIONAL SYSTEMS: AUTOMATIC CORRECTION FOR ATMOSPHERIC EFFECTS IN RESOURCE DATA

$$L_{obs} = \frac{\tau\rho}{\pi} E_o + Lp$$

where L_{obs} = sensor observed radiance

τ = atmospheric transmissions

ρ = ground surface bidirectional reflectance

E_o = incident total irradiance at ground surface

Lp = "path radiance"

The attenuation of ground radiance ρE_o may arise from two sources -- aerosol scattering and absorption. As a general rule, the scattering predominates in the atmospheric windows at short wavelengths ($<1.0\mu m$) and absorption is negligible except in the ultraviolet. At wavelengths beyond $3\mu m$ scattering is generally less important than molecular absorption. In fact, regions of high absorption by water vapor and carbon dioxide define the limits of most atmospheric windows. Thus equation 1 is a general equation for both thermal ($>4\mu m$) and reflective ($<4\mu m$) regions of the spectrum. Table 17 describes the atmospheric model.

One effect which has not yet been mentioned is the spatial effect of blurring edges. Because of atmospheric scattering, high resolution sensors will lose resolution. This same effect makes objects tend to look like the background in which they are imbedded (Nalepka's "green haze" effect - reference 1). Resolution degradation is probably not serious for most of the spaceborne scanners now contemplated. The effect on cameras may be more pronounced, and analysis of the Skylab S-190B sensor data may reveal the magnitude of these effects.

All the radiometric effects in equation 1 are functions of the atmospheric state at each point in the scene. For a scene with homogeneous atmospheric state the transmission function is generally symmetric about nadir. But the path radiance term, derived from scattering processes, is generally not symmetric about the nadir. Its precise behavior depends on sensor look angles relative to the solar position. It will be shown that the variation of τLp over

DESCRIPTION OF ATMOSPHERIC MODEL

THE BASIC RELATION IS

$$L_{OBS} = \frac{\rho E_o}{\pi} T + L_P$$

WHERE L_{OBS} = RADIANCE RECEIVED BY A SENSOR IN ORBIT,

T = ATMOSPHERIC TRANSMISSION

ρ = GROUND SURFACE BIDIRECTIONAL REFLECTANCE (E. G., CANOPY REFLECTANCE)

E_o = TOTAL INCIDENT IRRADIANCE AT GROUND

L_P = PATH RADIANCE

- THUS ATMOSPHERE AFFECTS GROUND SCENE (ρE_o) THRU ATTENUATION (T) AND ADDITIONAL SCATTERING (L_P) IN THE SENSOR FIELD OF VIEW
- T SYMMETRIC WITH SCAN ANGLE θ
- L_P (PATH RADIANCE) DEPENDS ON SCAN ANGLE AND SOLAR ILLUMINATION, HENCE NOT SYMMETRIC ABOUT NADIR
- BAND AVERAGED RESULTS FOR ERTS-1, FOR NORTH DAKOTA SHOWN IN FIGURES 1-3. (ANGLE EFFECTS FOR ERTS-1 SMALL, 11^{o} FOV, BUT LARGE FOR AIRCRAFT)
- IF CONTRAST AT GROUND C_O, AT SPACECRAFT C_H THEN RATIO C_H/C_O IS CALLED CONTRAST TRANSMITTANCE. THIS IS THE CONTRAST REDUCTION CONTRIBUTED BY THE ATMOSPHERE. EFFECT SIMILAR TO FIGURE 1.
- COLOR BALANCE SHIFTS CAUSED BY THE ATMOSPHERE TEND TO CONFUSE INTERPRETERS

the scene (as computed by an atmospheric model used at ERIM) is fairly small for the small range of look angles used in ERTS and Skylab sensors but large for typical aircraft sensors.

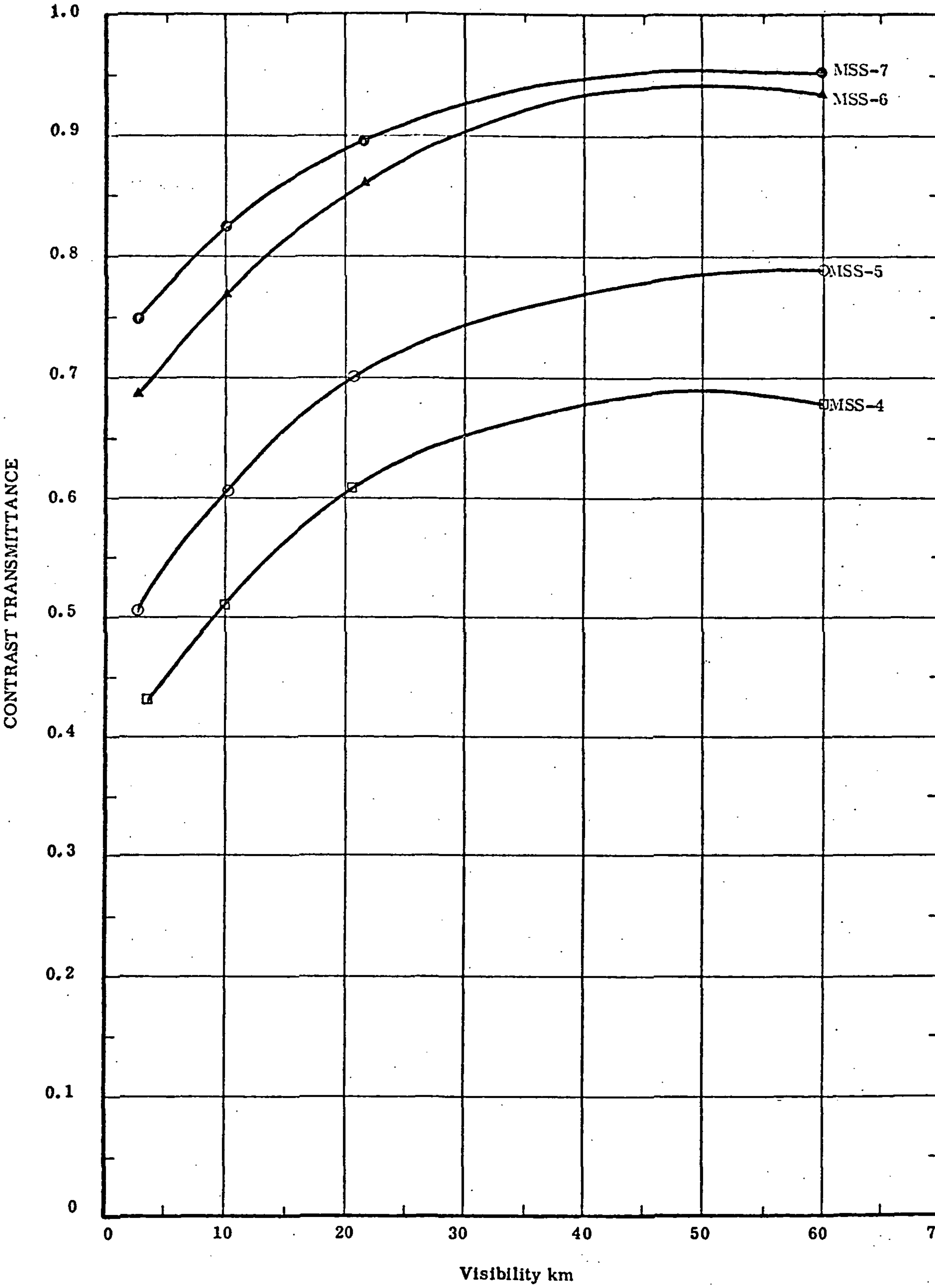
Atmospheric Effects on Photographic Systems

Atmosphere affects the quality of photographs taken from high altitude and from space in three ways. First, because of atmospheric attenuation and scattering the contrast between two ground objects is reduced. This contrast reduction is greater in the blue than in the red because of greater path radiance in the blue. Second, exposure times for effective terrain photography have to be modified over those which would be used in ground photography, and the amount and direction of change depend on the atmospheric state. There is some planned use of models of atmospheric effects to determine proper exposures for S190A and B experiments on Skylab. Third, since the atmospheric path radiance is a function of wavelength, there may be a general shift (usually towards the blue) of the colors of objects photographed through the atmosphere. This was apparent in early Gemini space photography before proper color-correcting filters were devised.

Contrast reduction can be computed from equation 1, assuming that τ is an attribute of the object of interest and Lp is determined primarily by the background. The contrast transmittance is

$$C_T = \frac{1}{1 + \frac{Lp}{L_B \tau}}$$

The dependence on the path radiance shows why the contrast ratio is reduced - under poor atmospheric visibilities or at short wavelengths. Typical values for the contrast transmittance for the four ERTS-1 MSS bands (which also correspond to four possible S-190A photographic bands) are shown in Figure 11. The calculations of atmospheric attenuation and path radiance were made using a model developed by R. E. Turner of ERIM (Reference 2). The atmospheric state is characterized by a ground visibility, and a standard distribution function of atmospheric aerosols (Elterman) is assumed. Also, molecular absorption is ignored. For the case



CURVES SHOWING CONTRAST TRANSMITTANCE AS A FUNCTION OF VISIBILITY FOR ERTS - 1 BANDS AND GREEN VEGETATION BACKGROUND

FIGURE 11

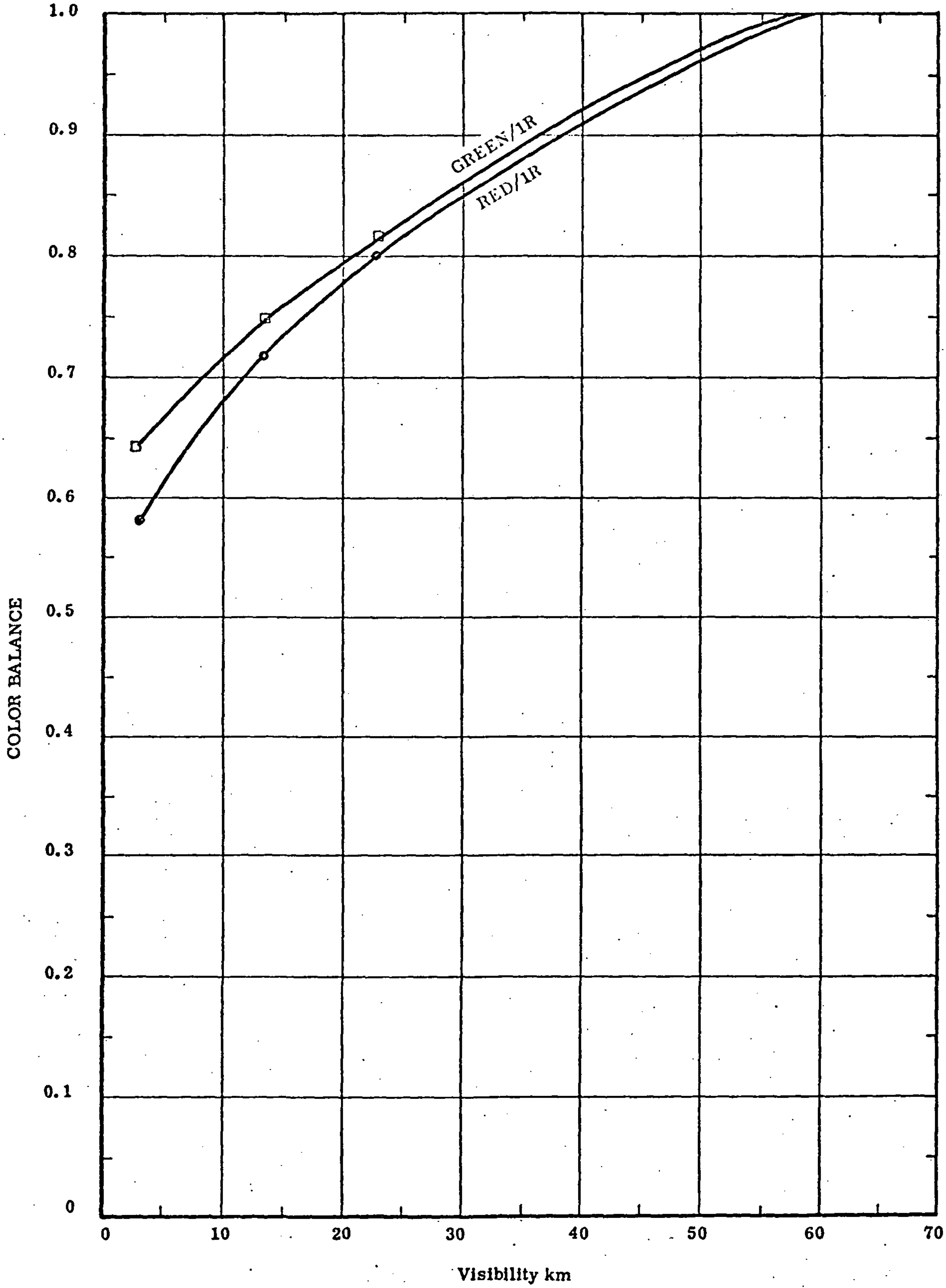
showing, a green vegetation background was assumed. Calculations were made for North Dakota on June 1 at 0930 hours. CDT. (Reference 3).

The color balance effects may be expressed as a ratio of band to band radiances from a spectrally flat surface viewed through the atmosphere. The smaller the ratio, the farther the color balance departs from true. Figure 12 shows color balance shifts of green/infrared and red/infrared for the same conditions as in Figure 11 normalized to 1 at 60 km visibility. Color balance shifts in the green may be quite severe at low atmospheric visibilities. These color balance shifts are important for they hamper the photo interpreter in identifying scene objects when his knowledge of what they should look like is based on low altitude aerial photography. In wide field of view camera systems, variations color balance across the scene tend to confuse the photo interpreter.

These discussions and the examples shown illustrate that the atmosphere plays an important role in the collection of good quality photography from space. Although the emphasis is on multispectral scanners and associated processors for solutions to many problems, the value of correlative photography, especially in the equipment debugging stage which is planned for the Shuttle, should not be underrated.

C. ATMOSPHERIC EFFECTS ON SCANNER DATA

All of the photographic system atmospheric effects are present in the scanner system. Contrast reduction may be called atmospheric attenuation and haze may be called path radiance, but the effects are qualitatively the same. The effect of attenuation and path radiance on analysis outputs of scanner data depend on what analysis schemes are used. For this discussion, we initially assume that a conventional multispectral signature pattern recognition device is being used to process the raw data to prepare maps of objects of interest that are both qualitatively and quantitatively as good as possible. A further function of this processor



COLOR BALANCE SHIFTS VS VISIBILITY
FOR GREEN VEGETATION BACKGROUND

FIGURE 12

is to determine the areas of various scene constituents. Later, comments will be made on the effects of atmosphere on some estimation algorithms.

Since pattern recognition devices work on the differences between spectral signatures and these signatures are assumed noisy, the effects of atmosphere on this sensor-processor combination are different than for the photography case. First, path radiance in any channel adds a constant signal level to all data (if the path radiance is constant over the scanner field of view); but this of itself causes no change in performance of the pattern recognition processor because the differences between signatures are unaltered. If path radiance changes across the scanner field of view or from the training area to the area to be mapped, processor performance will be adversely affected, because the assumption that the spectral radiance signature of a scene object is unique and descriptive of that object does not hold if path radiance varies.

Similarly, variations in transmission will adversely affect pattern recognition processor performance by reducing the separation of spectral signatures. This reduction in separation and shift of all the signatures to lower radiance levels will lead to misclassification of scene objects. The amount of tolerable shift from training conditions is a function of the application -- applications requiring recognition of more similar objects are more sensitive to atmospheric effects.

There has been a lot of study aimed at reducing the atmospheric effects to a point where reliable processing of large blocks of data can proceed (references 4,5). One effect of atmosphere cannot be corrected, and this forms an upper bound to the improvement which the "preprocessing" techniques can make in the performance of pattern recognition processors. All sensors respond to the observed radiance of Equation 1. In some sensors, particularly photomultipliers, the level of noise on the detector signal is directly related to the total observed radiance. Noise is an inevitable product of the detection of radiation and with well designed electronics, the detector noise can be the limiting noise source in the system. The noise, in turn, sets a limit to the performance of pattern recognition devices. Qualitatively,

spectral signatures whose differences are less than the noise level are hard to separate, while those whose differences are greater than the noise level may be easy to separate if their variation is small. Path radiance adds not only a constant signal level to the detector signal, but also noise. Attenuation reduces the separation of signatures so that this increased noise becomes a more important limit of the separability of signatures. Even if the additive and multiplicative effects of path radiance and attenuation, respectively, are completely removed, the noise will act to reduce processor performance.

The effects of transmission and of the increased detector noise caused by path radiance are quantized in systems where the detector signal is digitized before transmission or recording (e.g., MSDS or ERTS-1 MSS). For example, at extremely small signature separations, a reduction in atmospheric transmission might cause signatures to have identically the same mean in a digitizing system even though a mean difference (less than one quantizing level) existed in the raw detector signals.

Atmospheric effects play an important role in the design of dynamic ranges of spaceborne scanner systems. Unlike photographic systems, scanner systems usually saturate when signal levels exceed design limits. When saturation occurs, data is lost. Elaborate compensation schemes to prevent saturation may be devised, but usually at a compromise to system linearity or noise performance. (For example, a logarithmic compressor could be used to widen the dynamic range of the sensor, but the removal of this logarithmic characteristic probably could not be done as precisely as most processing people would wish). The scanner system is limited on the low side by noise performance of detectors and electronics and on the high side by system dynamic range (this includes detectors). To properly design system dynamic range not only must the range of signals from the objects of interest be considered, but the range of atmospheric conditions under which these objects are to be observed.

Three examples of model calculated atmospheric effects on the ERTS-1 multispectral scanner are shown in Figures 13, 14, and 15. These curves are taken from a paper by Sharma. (Reference 3) Calculations were made of transmission and path radiance for a green vegetation scene in North Dakota using a model developed by R. E. Turner. (Reference 2,4)

Variations in path radiance and transmission with scan angle ($\pm$ 5.5°) of the ERTS sensors was found to be negligible compared with the variation of these quantities with visibility. (The visibility is used to characterize the atmospheric state in Turner's model). Further calculations were made of the total radiance which a scanner would see from water. For this study, water was assumed to be a 4% flat reflector.

Figure 13 shows the behavior of transmittance versus visibility and indicates that greatly lowered transmission can be expected under low visibility(6 km) conditions, especially in the green. Whether or not the reduced transmission affects the ability of a pattern recognition device to separate objects depends on the problem. But certainly pattern recognition device performance will be compromised if one is looking through a 6 km visibility atmosphere and attempting to delineate crop disease of stress.

The behavior of path radiance with visibility is shown in Figure 14. As visibility decreases, the path radiance increases and very sharply at lower visibilities. The increase in the green is again greater than in the red and infra-red because of the greater scattering in the green regions.

The total radiance from water, Figure 15, plotted as a function of visibility is seen to be dominated by path radiance especially in the green and at lower visibilities. The example shows that sizable contributions to the total radiance observed may come from the atmospheric path.

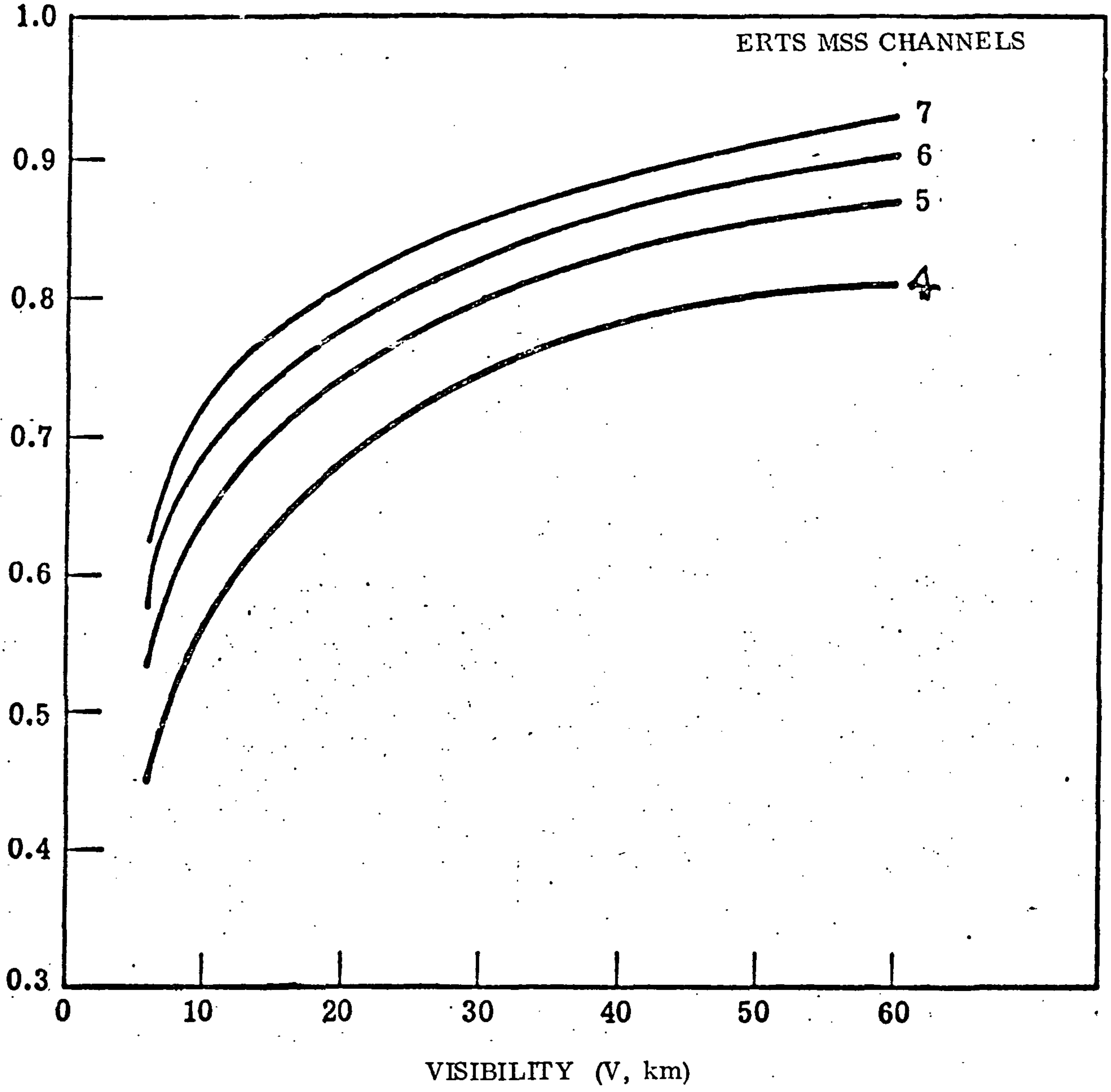


FIGURE 13. TRANSMISSION OF THE ATMOSPHERE VERSUS VISIBILITY FOR NORTH DAKOTA AUGUST -- GREEN VEGETATION BACKGROUND

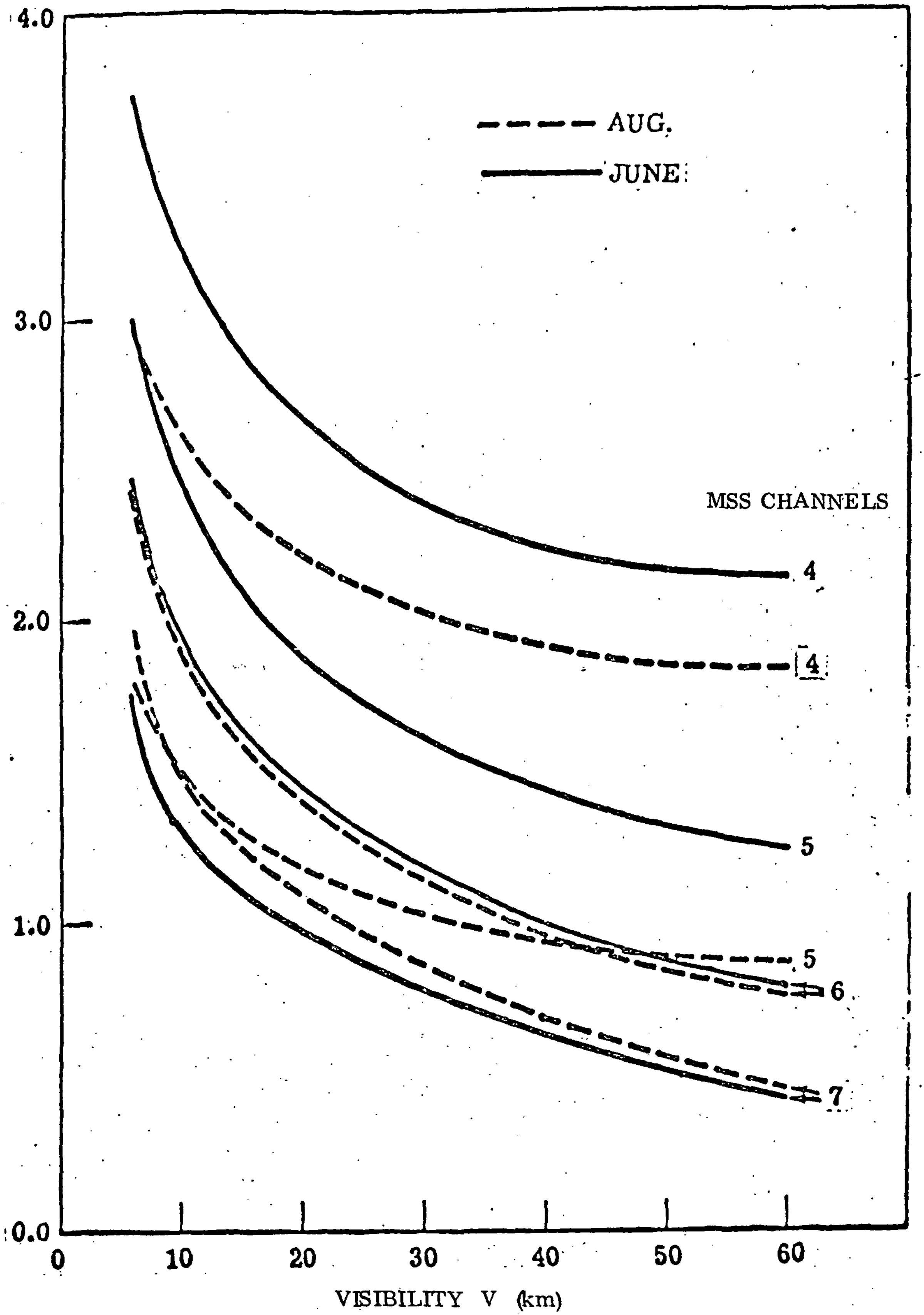


FIGURE 14. PATH RADIANCE (L_p) FOR 1 JUNE AND 1 AUGUST

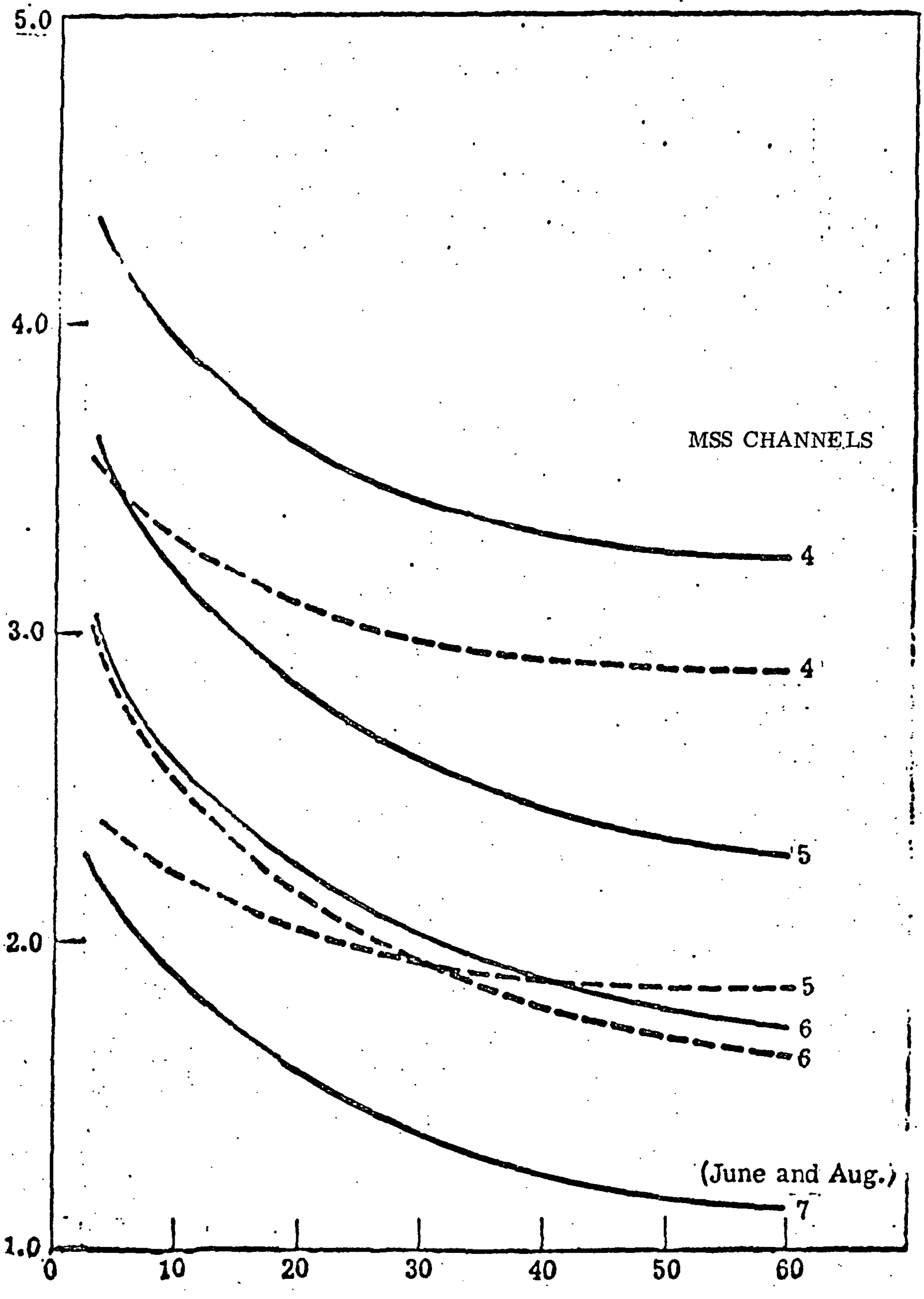


FIGURE 15. TOTAL RADIANCE (L) FOR JUNE 1 AND AUGUST 1

Atmospheric Effects on Estimation Algorithms

The effects of reduced path transmittance and increased path radiance with reduced visibility also affect estimation algorithms used to process multispectral data.

Suppose, for example, one is trying to estimate water turbidity by calculating the equivalent reflectance of the water in the green band, then converting this reflectance to turbidity by an equation derived from aircraft or ground measurements. Suppose, for simplicity that the relationship between turbidity and equivalent reflectance is linear. The uncompensated atmospheric path radiance will tend to bias turbidity estimates high and reduced atmospheric path transmission will tend to compress the spread of turbidity estimates between high and low turbidity water. Unlike pattern recognition devices where small uncompensated variations in path radiance or transmission may not cause any errors in recognition, these uncompensated variations always cause some error in estimate. The challenge is to design estimators which are relatively insensitive to the residual atmospheric effects present after compensation.

D. IMPLICATIONS FOR SHUTTLE

It is clear, both from these model calculations and limited experience with ERTS-1 data to date that atmospheric effects will be present in both photographic and scanner/radiometer data collected from satellites. Further, with operator directed instruments such as S-191,* the range of atmospheric effects will be greater because of the larger range of angles over which these devices operate. If a small field of view is set to track an object over a sizable range of view angles, changes in atmospheric effects almost certainly will occur during the tracking.

* Infrared spectrometer, Skylab Earth Resources Experiment Package.

Four points can be made about atmospheric effects on shuttle systems:

1. An appropriate range of atmospheric effects should be considered during the equipment design phase of instruments to be used on the Shuttle so that the proper dynamic range may be selected.

2. Any processing or estimation technique to be used on Shuttle-collected data (whether implemented on the spacecraft or on the ground) should have not only the ability to compensate data for atmospheric effects but also be reasonably insensitive to residual atmospheric effects left after compensation.

3. There may be certain superficially clear atmospheric conditions under which usable Shuttle data cannot be collected. This may occur because a) the astronaut cannot acquire objects to be tracked because of increased path radiance and reduced transmittance or b) the acquired data, when processed has error rates (caused by imperfectly compensated atmospheric effects) which are too large for the user.

4. Either a general purpose atmospheric sounder (and experience using its data to deduce atmospheric state) or meterological information may be required to deduce the atmospheric state if calculated corrections are to be made to data. The atmospheric sounder has considerable appeal in deducing atmospheric state over a) remote areas where meteorological information is not available or b) over metropolitan areas, where changes of atmospheric state over 1 km distances may be sizable.

5. Thus Shuttle Sortie Missions could be key steps in the development of an understanding of the atmosphere and may include atmospheric science experiments such as:

a) Spectrophotometric and polarimetric observations of the minor gas constituents and particulate matter and their altitude distribution.

b) Study of specific window regions or spectral regions with considerably better accuracy than that observable from automated satellites. Since the Sortie has viewing flexibility and large weight carrying capacity subjects such as ozone dynamics and UV-absorption, exhausts from supersonic airplanes and dynamics of their dispersal can be studied.

c) Study of pollution sources, distribution of pollutants in the atmospheric layers etc., can be performed with specialized sensors and instruments.

Collectively large compliment of instruments in the sense of a suitable optics laboratory to cover the wavelength regions of interest can be carried on board the Shuttle. Some of these facility concepts have been discussed earlier. This can cater to the atmospheric correction needs for the Shuttle-acquired data under a variety of viewing conditions as well as for the development of a general purpose atmospheric sounder to cater to the need of corrections in the automated satellite acquired data. Table 18 summarizes the relevance of atmospheric effects to the Shuttle.

RELEVANCE TO SPACE SHUTTLE

- DESIGN AND USE OF EQUIPMENT ABOARD SHUTTLE SORTIE MISSIONS OUGHT TO INCLUDE CONSIDERATION OF ATMOSPHERIC EFFECTS IN ORDER TO REDUCE CLASSIFICATION ERRORS AND TO EXTEND TERRAIN CLASSIFICATION (GLOBALLY) IN AREAS USUALLY AFFECTED BY THE ATMOSPHERE
- ON-BOARD OR GROUND DATA PROCESSING TECHNIQUES SHOULD INCLUDE ATMOSPHERIC CORRECTIONS
- IN TRACKING TYPE EXPERIMENTS, PATH RADIANCE INCREASE MIGHT LIMIT ASTRONAUT'S ACQUISITION CAPABILITIES
- NON-UNIFORM ATMOSPHERIC EFFECTS MAY INTERFERE WITH DESIRED OBSERVATIONS (FOG AND WATER IDENTIFICATION) AND INTERPRETATIONS DUE TO COLOR BALANCE SHIFTS
- SHUTTLE SORTIE MODE IS KEY R&D PHASE IN DEVELOPING UNDERSTANDING OF ATMOSPHERE AS IT AFFECTS REMOTELY-SENSED DATA. ATMOSPHERIC SCIENCE EXPERIMENTS NEEDED INCLUDE:
  - SPECTROPHOTOMETRIC AND POLARIMETRIC OBSERVATIONS TO DETERMINE MINOR GASEOUS AND PARTICULATE MATTER AND THEIR ALTITUDE DISTRIBUTION (VERY LITTLE IS KNOWN ON OXIDES OF NITROGEN, SULPHUR, ETC.)
  - STUDY SPECIFIC WINDOW REGIONS OR SPECTRAL REGIONS WITH CONSIDERABLY BETTER ACCURACY (SUCH AS OZONE DYNAMICS AND UV-ABSORPTION, AND LAYERING OF EXHAUSTS FROM SUPERSONIC TRANSPORT) THAN FROM SATELLITES, SORTIE HAS VIEWING FLEXIBILITY
  - STUDY OF POLLUTION/DISPERSION, ETC., WITH THE USE OF SPECIALIZED INSTRUMENTS
- SORTIE FACILITY MODE/CAN AID DEVELOPMENT OF GENERAL PURPOSE ATMOSPHERE SOUNDER TO DETERMINE THE ATMOSPHERIC STATE AND DEFINE OPERATIONAL OBSERVATIONAL PARAMETERS FOR ROUTINE ATMOSPHERIC CORRECTIONS TO AUTOMATED SATELLITE DATA

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6. F.J. Thomson, "User Oriented Data Processing at the University of Michigan", NASA Third Annual Earth Resources Program Review, Vol. II, December 1970.

CHAPTER VII

INTERNATIONAL ASPECTS

A. GENERAL

As with the Earth Resources Technology Satellite and the Skylab, Shuttle Sortie missions will also pass over a large portion of the world's land surface. In polar orbits, the Shuttle Sortie mission will cover the globe completely. Thus, for each orbit, there will be significant portions available for taking data over other countries. This capability of the Sortie missions can be exploited in two modes: firstly, in a true sense of participation with the industrially developed nations of the world for providing them with means to carry out surveys of their natural resources, and, secondly, as a contribution by the U.S. toward natural resources survey requirements of the developing nations. Each of these aspects will be discussed in the following. However, it is extremely desirable, in the light of the long lead-time required for participation in the manned space flight program, to evolve a policy and methodology for participation by other nations in the Space Shuttle program. It is well known today that since high technology goes hand-in-hand with geo-political realities, the possible effects of changing geo-political realities have to be incorporated in these policies and their impact on the Space Shuttle program has to be considered. Since NASA has a history of constructive participation in international programs, it is desirable that the same tradition be continued even more vigorously in the case of the Space Shuttle program and particularly for the study of natural and renewable resources in the Sortie mode.

For the first time the Space Shuttle Sortie mode of observation provides a true opportunity for participation by all interested nations in manned space flight which, up to now, was carried out only by the two most advanced nations. With the size of payloads and the frequencies of flights contemplated for the Space Shuttle, it seems that participation by many nations can take place at a level commensurate with the capabilities of the participating nations, i.e., from simply acquiring data relating to their countries to sending their instruments for the observations on-board the Sortie and even to the extent of building modules and hoping to send mission specialists on-board. The international aspects are summarized in Table 19.

TABLE 19

INTERNATIONAL ASPECTS

- U.S. HAS NEW AND UNPRECEDENTED CAPABILITY TO OFFER THE DEVELOPING NATIONS OF THE WORLD
- SORTIE BRINGS "PARTICIPATION" IN MANNED SPACEFLIGHT WITHIN REACH OF MANY COUNTRIES
- POLICY AND COMMITMENT TO GUARANTEED LAUNCHES IS NEEDED IN RETURN FOR COSTS INCURRED IF MULTI-NATIONAL PARTICIPATION ANTICIPATED
- A METHODOLOGY IS REQUIRED TO EVALUATE THE EFFECT OF CHANGING GEOPOLITICAL REALITIES AND THEIR IMPACT ON THE SHUTTLE PROGRAM
- TANGIBLE BENEFITS THROUGH TECHNOLOGICAL COOPERATION WITH DEVELOPED COUNTRIES WARRANT EXPLORATION
- PARTICIPATION BY OTHER NATIONS IS DESIRABLE IN BUILDING AND/OR FURNISHING MODULES, COMPONENTS, SUBSYSTEMS AND PAYLOADS WHEREVER MUTUALLY ADVANTAGEOUS (ESRO, JAPAN, ETC.)
- ROLE OF INTERNATIONAL ORGANIZATIONS (UN, WORLD BANK, ESRO, ETC.) NEEDS DEFINITION IN THE USE OF SORTIE AS A FACILITY OR AS SUPPORTING SPECIFIC SURVEYS FOR DEVELOPING REGIONS AS NEEDED, INCLUDING INTERNATIONAL SUPPORT OF CONTINGENCY MISSIONS.
- POLICY DEVELOPMENT IS NEEDED REGARDING POSSIBLE SALE/LEASE ARRANGEMENTS (TO OTHER ORGANIZATIONS) OF THE ORBITER AND SORTIE USE AS SPACE TRANSPORTATION SYSTEM
- EARLY DEVELOPMENT OF MOCK-UPS AND INTERFACE/SUBSYSTEM DETAILS REQUIRED FOR ASSESSING, PLANNING AND BUILDING OF PAYLOADS/SOFTWARE SYSTEMS BY OTHER NATIONS

B. PARTICIPATION BY INDUSTRIALLY ADVANCED NATIONS

Initially, a systematic screening of the disciplines relating to earth resources survey has to be carried out to identify problems of global interest and the problems of interest to the industrially developed nations. Only when the mutual interest which leads to tangible benefits are present, can such technological cooperations occur successfully. There are many areas such as the land use surveys, study of forests and hydrology where such benefits can be identified. Next, a policy development is needed for defining the criteria under which participation in the sortie experiments by other nations would be encouraged. These include the initial terms of the experimental participation which could essentially be limited to feasibility demonstrations of the usefulness of Sortie mode for obtaining data relating to earth resources. The data could be provided initially free of cost for a limited period just like the ERTS experimental system. However, for the Sortie to become a long-term stable operation, it is also necessary that some considerations be given to the question of rent, sale or lease of the facilities on-board the Sortie, as well as to the question of the cost of the mission for acquiring the resource data. The procedures for arriving at the cost in such highly innovative technologies will also have to be worked out. These procedures can be extended later even to the case of the modules and the orbiter if interested nations come forward with requests for purchase or lease of these major systems in the future periods.

Even though the Sorties are relatively flexible and require relatively short notice to carry out a given mission, the complex technologies employed necessitate parallel planning and interface definitions with the users specially in the area of earth resources surveys. These would enable early development of mock-ups, interfaces, and subsystems which will be useful in assessing, planning and building of payloads and also provide adequate time for participation by other nations where the time-scales for achieving the same technical capability might be different than those in the U.S.

Participation by other nations and organizations is desirable in completing the components, subsystems, payloads or modules wherever it is mutually advantageous to do so. The situations where the Sortie modules can be built are those where institutions or nations involved have sophisticated industrial capabilities such as is in the case of ESRO, Japan, etc. The other nations which do not want to undertake

such major activities as the building of modules for earth resources survey can either build a subsystem or payload relating to their interests which can be integrated in a module for carrying out earth resources observations. The instrument development activity which has been discussed in the earlier chapters can benefit substantially if the capabilities of the many nations can be pooled for this purpose.

Many international organizations have needs for surveys, specially for carrying out joint, binational or multinational, projects. Some of these future surveys could assess regional-scale pollution for example, or carry out surveys to ensure efficient use of shared fresh water supplies. In other situations, the survey projects could be initiated by industrially advanced nations and international organizations to carry out pre-investment evaluations.

The U.N., the World Bank, etc., often have needs for resource information over large areas. The Shuttle Sortie mode, with a modular instrument facility is specially suited to carry out such surveys because these are only one or two time requirements so that the availability and programmability of the Shuttle appears particularly attractive in such situations.

C. ISSUES OF SPECIFIC INTEREST TO DEVELOPING NATIONS

It is not always possible to separate the needs of the developing countries and those of the developed ones since the need for resource information is often common among them. For example, urban problems confront the developing nations also and so does the need for water quality assessment. The Space Shuttle Sorties will have sufficient weight, power and volume available so that microwave systems can be included to provide an all weather capability. Some of these situations such as monsoon, typhoons, storms and hurricanes generate emergency information needs. These often occur in the developing regions of the world, including the tropical regions. The Sortie, with such specialized sensors, can help in quick assessment of the damage from such emergency situations and, if properly planned, can communicate with the areas through data relay satellites.

In the case of industrially advanced countries, there already exist communication and information systems which are ground-based and which can quickly disseminate the emergency information to the whole country. However, this is not the case for

developing nations where there are no rapid, universal information systems; therefore information received more directly from the Sortie platform can be extremely useful. Next comes the question of how this information can be relayed back to those areas where damages from such emergency situations arise and to the policy makers or resources managers who have to plan rescue or supply operations in the affected areas. It is assumed that there will be data relay satellites in the Space Shuttle communication system. In addition, if some regional communication and data receiving stations can also be planned, along the line of INTELSAT stations, then emergency as well as resource information can perhaps be transmitted more quickly to the desired areas. However, a smooth operation of such systems will require considerable effort and advance planning.

As mentioned before, the developing countries also have need for their own pre-investment surveys. This may be undertaken using the Sortie if the requirements cover large areas and varying spatial resolutions, etc. These can be grouped with surveys to be carried out over several nations or with the missions planned to carry out surveys for the industrialized nations and thus the incremental cost of carrying out such surveys for developing countries might be bearable by them.

The Space Shuttle Sortie missions will be carried out for purposes other than earth resources survey, e.g., atmospheric studies or astronomy. If metric quality mapping cameras could be routinely incorporated aboard Shuttle flights, this would provide a film return capability with each Shuttle mission thus providing opportunities for the first time to map large areas of the world (especially in the developing countries) with cartographic standards.* However, the questions to be further examined in this connection are connected with variable scales depending upon the orbit for each mission. The ground coverage expected from such cameras for several typical missions, the possible gimbal mounting of such systems for increased flexibility in an earth looking mode, etc., also need further consideration. The incorporation of such camera systems in a pallet form may be useful. During ascent and descent phases, there may also be some opportunities for specialized high resolution coverage of some areas.

The classification techniques, especially those exploiting the canopy and atmospheric models, discussed in the earlier chapters also have particular applicability to

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*Discussions with Dr. M. Molloy, NASA Headquarters, December 1972.

the developing regions. However, the variation in cultivation practices and periods of growth have to be incorporated into the model if the classification techniques are to be extended to these regions. The Sortie modes, with their inherent solar illumination and look angle variations, offer an outstanding opportunity to develop and understand domestic canopy type vegetative models so that transfer of these models to the differing cultivation practices of developing nations can be accelerated without recourse to extensive ground truth measurements.

Thus, the advantages of the Shuttle such as flexibility and programmability may be relatively more useful to the developing nations since they do not have conventional resource information gathering systems. This is particularly relevant to emergency situations where resources are damaged or otherwise affected.

The Shuttle Sortie mode thus has a promising role to play in the international sphere. It offers nations and the international community of resource scientists and managers the unique opportunity for experimentation and tests of their ideas without requiring the development of permanent, more expensive space hardware. For the case of a Sortie, the investment can be limited only to a few missions in order to test and evaluate the ideas and only those systems which prove successful in the Sortie R&D mode need be considered further for permanent or long term deployment as operational systems.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The use of the Shuttle Sortie mode for earth observation applications was investigated and its feasibility for applied research and instrument development was appraised. These results indicate that the Shuttle Sortie missions offer certain unique advantages and that specific aspects of earth applications are particularly suited to the Sortie mode.

1. Advantages of Sortie Missions

The Shuttle Sortie missions will offer advantages for:

- Specific experiments
  - Development, verification and utilization of resource models dependent on sun angle and/or look angle, e.g., canopy models
  - Atmospheric correction of data and application to improved model utilization
- Sensor development
- Selected resource application objectives
- On-board processing development, including interactive aspects
- Developing countries
  - The Sortie can assist rapid assessment and communication of damage where other systems are lacking
  - All-weather emergency needs can be fulfilled by the Sortie (i.e., monsoons, typhoons, hurricanes, etc.)
  - Pre-investment surveys may be undertaken over large areas, quickly, at high resolution
  - More rapid development of canopy and atmospheric models using Sortie missions can facilitate the extension of U.S. terrain classifications, e.g., regional agriculture and multilayered forest areas, to other areas with less ground truth measurement requirements
- Contingencies and emergencies

2. Pertinent Characteristics of Sortie Missions

The central focus of the foregoing conceptual study effort has been to define a rationale for the matching of Shuttle Sortie mission capabilities with recognized program objectives and user needs in the Earth Resources Survey Program. Those sortie mission characteristics which are of special significance include:

- o Programmable viewing angles
- o Sun angle variations
- o Instruments may be substituted or sequenced on subsequent missions
- o Orbital parameters may be varied, e.g., inclination, altitude
- o Manned capability
  - Carry mission specialists
  - Acquire and track targets
  - Edit data and rapidly modify viewing program
  - Select, repair, adjust sensors
- o Limited operational use without commitment to a continuous system
- o Quick deployment for contingency missions

3. The Sortie hence is of particular usefulness where:

- o Seasonal or less frequent sensing is adequate
- o Data is not available from other satellites
- o An on-board mission specialist is required
- o On-board data processing is desirable and the manned interface is important
- o Low altitude orbit is preferred
- o A few observations will provide sufficient data
- o Rapid assessment of short-duration phenomena is required.

B. RECOMMENDATIONS

1. Studies of common factors inherent in most earth resources data should be pursued. These include studies of processing techniques, information correlation techniques and development of atmospheric models. These studies will facilitate timely utilization of Shuttle-Sortie-acquired information.

2. Significant experiments which exploit unique characteristics of the Sortie, such as the development, verification and application of vegetative canopy models, should be defined in detail.

3. The role of Shuttle Sortie missions for both developed and developing countries should be further defined, including an assessment of potential economic impact.

4. Significant efforts should be undertaken to acquaint potential national, international and industrial users with the capabilities of the Sortie and concurrently, enable NASA to perceive user problems clearly enough to ensure properly-phased effective utilization of this new and flexible capability.